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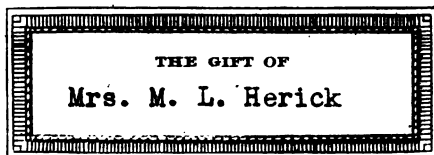
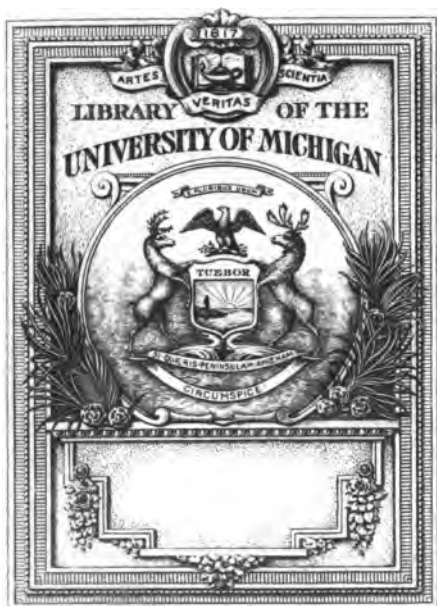
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1850

J. W. L.

AN
INTRODUCTION
TO THE
ATOMIC THEORY,
BY
CHARLES DAUBENY, M. D. F. R. S. &c.
PROFESSOR OF CHEMISTRY AND OF BOTANY
IN THE UNIVERSITY OF OXFORD.

Πάντα μέτρον, καὶ ἀριθμὸς, καὶ σταθμὴ διέταξας.

SECOND EDITION, GREATLY ENLARGED.

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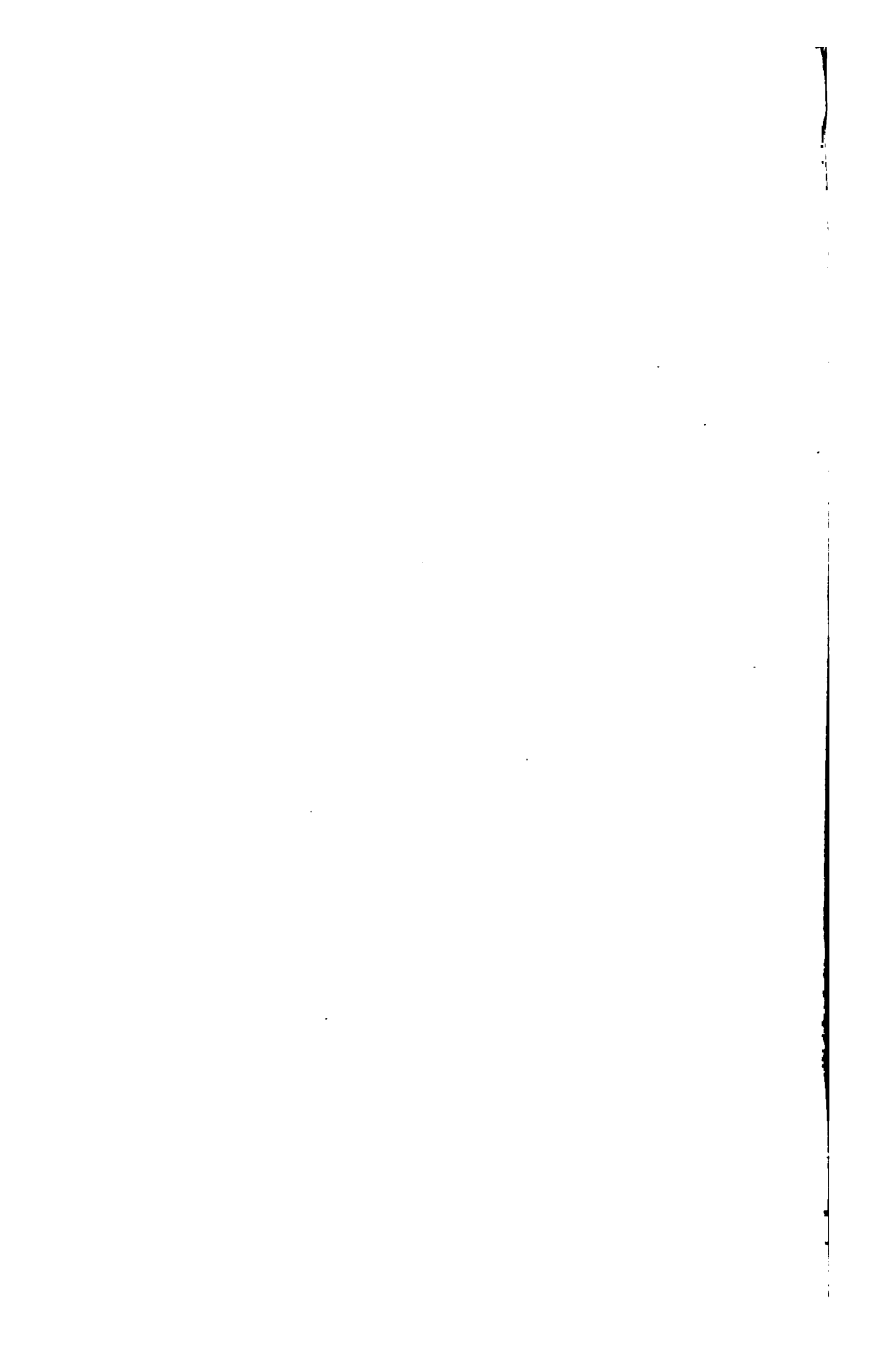
M.DCCC.L.



TO
THE MEMORY OF
JOHN DALTON, F. R. S.

Late President of the Literary and Philosophical Society of Manchester,
Corresponding Member of the Academy of Sciences of the Royal Institute of France,
and Honorary D. C. L. of the University of Oxford,

THE FRAMER OF A THEORY
WITH RESPECT TO THE MODE OF COMBINATION BETWEEN
BODIES,
WHICH STANDS FOREMOST AMONG THE DISCOVERIES OF
THE PRESENT AGE,
FOR THE UNIVERSALITY OF ITS APPLICATIONS,
AND THE IMPORTANCE OF ITS PRACTICAL RESULTS ;
HOLDING THE SAME KIND OF RELATION TO THE SCIENCE
OF CHEMISTRY,
WHICH THE NEWTONIAN SYSTEM DOES TO THAT OF
MECHANICS ;
AND THROWING LIGHT,
NOT ONLY UPON ALL THE ORDINARY SUBJECTS OF
CHEMICAL INVESTIGATION,
BUT EVEN UPON THOSE MORE SPECULATIVE QUESTIONS
WITH RESPECT TO THE CONSTITUTION OF MATTER,
WHICH SEEMED TO LIE BEYOND THE REACH OF
EXPERIMENTAL INQUIRY ;
THIS ESSAY,
WHICH IN A LESS MATURE FORM
WAS HONOURED BY HIS APPROVAL,
IS NOW INSCRIBED,
AS A SLIGHT TRIBUTE TO HIS POSTHUMOUS REPUTATION,
BY HIS FORMER FRIEND, AND DEVOTED ADMIRER,
THE AUTHOR,



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Mrs. M. L. Herrick
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7-31-45 RE

PREFACE.

THE first edition of this little Treatise, comprising a sketch of the opinions entertained by the most distinguished chemists with respect to the

For the Observatory library.
S.P.Langley's personal copy, given
him by his brother, J.W.Langley,
who was a student at Harvard and
at the U.of Mich.

with the Atomic Theory, or

I had proposed myself as the humble expounder, could not but be admitted to run counter to many of those opinions with respect to the chemical properties belonging to matter in general, which at this earlier period had obtained a tacit, if not a distinct recognition.

In order to shew that such was the case, my Supple-

ment commenced with a brief summary of those principles which I conceived would have been commonly admitted at the time of the publication of the original Essay; not that I meant to imply, that all the facts that tended to impugn them had been of such recent discovery, but only that the inferences to which they led, had either at that time not been deduced, or at least had not received the general sanction of the scientific world.

The following were the propositions which, at this earlier stage of chemical inquiry, would have met perhaps with an almost unqualified assent amongst chemists:

1. Matter is composed of a number of particles incapable of further division (or of atoms), bound together by the force of cohesive attraction, and compound bodies are produced by the union of ultimate particles of different kinds of matter possessing an affinity one for the other.

2. There exists therefore a variety of elementary bodies, each of which is distinguished by the possession of certain fixed and unalienable properties, chemical as well as physical, so that the business of the analytical chemist is limited to the determination, of the nature of the several elements which enter into the composition of the substance he examines, and of the definite proportion they bear to each other.

3. The difference between one compound body and another can be referred only to two causes,—namely, either to their being formed of essentially different ele-

ments, or of the same elements combined in different proportions: so that all bodies possessing the same chemical composition must be regarded identical both as to *form* and *nature*—in physical as well as in chemical properties; whilst those which disagree, either in the nature, or in the proportion of their component parts, must be expected to differ likewise one from the other in both the above particulars.

4. Decomposition is caused by the approach of a foreign body, possessing a stronger affinity for one of the ingredients of a compound, than that which binds the latter mutually together, so that in every such case, the decomposing agent may be expected to enter into union with one or other of the elements of the combination which it destroys.

5. The water, which is found attached to many bodies, is essential to their crystallization, but does not materially affect their intrinsic properties; a salt perfectly divested of water being in no respect to be regarded as chemically different from one which contains it.

6. Organic bodies have their particles held together, partly by what is called the *living principle*, a principle, distinct from chemical affinity, and superadded to it, so that the laws which operate upon inorganic matter are in many instances suspended by its influence.

Hence it is idle to expect, that any of the various chemical compounds which result from processes taking place in the living body, can be produced by artificial means, they being themselves resolved into their component elements, or into simpler forms of combination,

so soon as the sustaining force, the principle of life, is abstracted.

It was the object of my Supplement to establish, that not one of the above propositions would pass at the present day uncontroverted; and consequently, that although nothing that had since been discovered tended in the slightest degree to subvert the great laws of atomic combination, laid down by the philosopher of Manchester, whose views I had taken upon myself to expound, still that chemistry had assumed quite a new aspect, since the period at which he first enunciated his Theory.

The present Treatise, which, inasmuch as it comprises the substance of both the former Publications—entering, both into the general laws of atomic combination, and into those novel positions in science which had grown up into maturity since their original promulgation—is entitled a second edition of the Introduction to the Atomic Theory, will be found, it is hoped, both more complete in its details, and more comprehensive in its general outline, than either of its prototypes.

Like these indeed, its aim and ambition is to tempt the man of leisure, whose education, according to the views current amongst us, would be considered as completed, into the alluring field of chemical research; and to lay open, to the Members of my own University in particular, a vast region of research, not less calculated, it is presumed, to reward their exertions, and to discipline the powers of the mind, than any of those which ancient literature had set before them.

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But, in addition to these objects, it likewise designs to offer to the regular student, what under the reforms now introduced into our system of academical instruction is likely to be demanded, certain greater facilities for acquiring that information, which in offering himself for examination in the school of Natural Science he will be expected to possess.

Nevertheless, in holding out this prospect, it will be right for me at the same time to guard against creating in the minds of my Oxford readers erroneous impressions with respect to the character and purport of the Work now presented to them. Although calculated, as I trust, to assist as well as to direct the student in his endeavours to master the science to which it relates, the Treatise in question is not of a nature wholly to supply the place of a text book, or to supersede the necessity of an occasional appeal to other sources of information.

To have answered these purposes, it should have been at once less discursive, and more elementary ; it ought to have abstained on the one hand, from entering upon any topics that do not fall strictly within the scope of the contemplated Examination ; and on the other to have distinctly explained all those principles and facts, with which every student will be expected to be conversant, but which, from their very rudimentary nature, are often in this volume assumed to be already known to the reader.

But although this little publication may not supersede the want of other Manuals, it will, it is hoped, enable the student often to content himself with a less

voluminous text book, than he would otherwise have been constrained to procure.

There is indeed in this country no lack of Treatises, capable of supplying almost every species of information which the student in chemistry can desire.

Such for instance are the "Elements," first published by the late Dr. Turner, and since edited by Dr. Gregory, with the aid, and under the sanction, of the illustrious Founder and Head of the great school of Giessen. Such too are the similar works of Professor Graham of the London University, and of sir Robert Kane of Cork, both names of such high eminence, that any testimony on my part to the value of their productions would be wholly superfluous.

But, as these standard Treatises naturally aspire to the rank of Systems of chemical philosophy, or Summaries of the existing state of our knowledge in all the departments of this widely spreading science, they necessarily embrace a vast mass of details, and make allusion to a large number of bodies, which can scarcely be expected to come within the cognizance of the mere tyro ; or indeed be made by him available to any useful purpose, from the reading of books alone, unassisted by a course of chemical manipulation.

It is probable, therefore, that many who aim at qualifying themselves for passing an examination in this branch of science, will rest satisfied with some one of those smaller compendiums, which confine themselves to the more generally important and interesting class of facts.

Such writings, however, of necessity enter more

briefly into the principles of the science than would be satisfactory to the students of this University in general. In their case, the science presents claims to attention, less from its bearings upon pharmacy, metallurgy, and the hundred processes of the arts and manufactures, than from the light it sheds upon the phenomena of the external world ; on the processes that are carried on on a great scale in nature, or which are exhibited in the structure of the globe, and in its animate or inanimate productions. A cheap and compact manual therefore, such as that of Fownes or Gregory, which dwelt sufficiently upon details for the purposes of the Oxford student, might pass too rapidly over those questions of general interest, which connect the science of chemistry with other branches of philosophy, and with those speculations of by-gone ages, with which his previous studies had rendered him to a certain extent familiar.

It is in supplying this gap that the present Treatise may perhaps be of use ; and the want of some Manual, which should exhibit in a more expanded form the great principles of chemical philosophy, detached as far as possible from those details, with which they are in a manner overlaid in the bulkier volumes alluded to, will be more clearly understood, by consulting some remarks on the " Correlation of the Natural Sciences," drawn up by the Author in the year 1848, with reference to the scheme for the extension and better management of the studies of the University, then in agitation, and since in great measure adopted by Convocation.

For although I would carefully guard against conveying the impression, that the University stands in any degree committed to the opinions expressed in that publication, yet I have the satisfaction of thinking, that the general principle therein contended for seems in harmony with the spirit of the enactments of the New Statute, so far as the physical sciences are concerned.

The leading idea then which runs through this Pamphlet, was to insist upon the distinction which exists in the scale of importance, between those branches of physical science, which were regarded as fundamental or primary, and those which were special or subordinate—the former including a knowledge of the general laws of matter; the special properties and relations of those bodies, which are either most familiar to us, most useful, or most generally diffused throughout nature; and the general laws which govern life, both as it exists in the animal and in the vegetable creation.

The Statute itself seems to recognise this threefold distinction, in enacting, that an acquaintance with the principles of two of these three branches of natural science, viz. Mechanical Philosophy, Chemistry, and Physiology, shall be required of every one who offers himself for examination in the school of Natural Science. And, as neither the characteristic properties of individual substances, nor the operation of vital forces, can be rightly understood without some acquaintance with the general properties of all matter, whether dead or living, it is fitly determined, that Mechanical Philosophy should be necessarily regarded as one of the two departments

of natural science in which the student must prepare himself for examination.

Mechanical Philosophy, Chemistry, and Physiology, therefore, according to the view I have taken in my Pamphlet, will require to be studied by all those who intend to offer themselves for examination in any one of the branches of Natural History, which I have denominated the special or subordinate sciences; it being evident, that the general principles of each must be deduced from the laws of one or other of the three that are regarded as fundamental.

Thus Geology draws its conclusions with respect to the present or past condition of the globe, partly from Mechanics, partly from Chemistry, partly from Physiology: Mineralogy, if treated crystallographically, is founded upon mathematical laws; if with reference to the uses and constitution of the several bodies which it describes, is mainly dependent on Chemistry. And the same remarks apply to Botany, Zoology and the rest.

An acquaintance with any one of these branches of natural history indeed, if limited to its mere technical details, would seem undeserving of academical distinction—in order to be recognised amongst the titles to honours in our University, it ought to be accompanied with such an insight into the principles of the three primary or fundamental sciences, as should enable the Candidate, to explain the causes of the phenomena which he states, to appreciate the grounds and importance of the general laws which he recognises.

Without wishing to impose my own views upon

others, I would submit to my readers, whether such be not the meaning of that clause in the Statute, in which it is laid down, "that an acquaintance with the principles of the three branches of natural science named above, and of some one of the physical sciences which fall under the above named branches of natural science, shall be required for honours;" and whether it may not be from thence inferred, that any one of the recognised departments of natural knowledge* would be allowed to establish a claim to university distinctions, provided it were accompanied with a competent knowledge of the three fundamental sciences upon which its generalizations are founded.

If such be a correct view of the provisions of the Statute, it is evident, that there will be very many amongst the students of this University, who, whilst they feel themselves called upon to master the great principles of chemistry, and to acquaint themselves with the properties of the bodies most generally diffused throughout the globe, and most instrumental in the grander phenomena of nature, will stop short of the minor details; and for these persons such a Manual as I here offer, coupled with some one of those smaller Compendiums which have been already named, may probably suffice.

For others indeed, who aspire to distinction in chemistry itself, and do not use it merely as a passport to other kinds of knowledge, the case is different.

* I mean those upon which courses of professional lectures are delivered.

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They of course will not be contented with so generalized a view of the phenomena as is presented in my volume, or with so partial and condensed a statement of the facts as that which the smaller epitomes supply. To such persons, however, not only a study of one of the more voluminous treatises already alluded to will be indispensable, but also a familiarity with the substances treated of, with their properties, and their relations to others—a familiarity scarcely to be obtained, except through the medium of a course of chemical manipulations; which accordingly now constitutes in other schools a part of every complete system of instruction in this science, and which, it is hoped, if not insisted upon here, will at least be strongly recommended to every aspirant to distinction in this most important branch of physical research.

Oxford, July 20, 1850,

term *atom* as applied to signify a substance supposed incapable of further mechanical division by any natural force—That this is the case with every species of matter when brought to a certain degree of tenuity was the opinion of Newton; though the opposite doctrine has been held by the Cartesians, and by some modern German metaphysicians I

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INTRODUCTION.

INTRODUCTION

TO THE

ATOMIC THEORY.

CHAPTER I.

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THE subject which I propose to consider in the present Essay, is one that appears to have perplexed mankind from the earliest dawn of philosophical inquiry, having exercised and baffled the ingenuity at once of the Hindoos, the Egyptians, the Phœnicians, the Greeks, the Schoolmen of the middle ages, and the still darker Metaphysicians of Germany.

It is also one that relates to bodies infinitely too minute to be objects of our senses, however sharpened by habits of observation, or assisted by the

most perfect mechanical contrivances, and which therefore, if brought at all within the compass of our knowledge, must be contemplated by the superior subtlety of mental vision alone.

Hence it may seem to be a question upon which the peculiar resources of modern science would avail us but little, and which ought therefore to be abandoned altogether by the experimentalist, as belonging to the exclusive province of metaphysics. And yet perhaps it will not be difficult to maintain, that there is a peculiar propriety in connecting such a discussion with the discoveries of modern chemistry, as being in itself eminently calculated to recommend the inductive method of research, since it shews how much light may be occasionally thrown upon the darkest subjects of human inquiry, by the determination of an assemblage of minute and apparently isolated facts.

What indeed can be a greater triumph for the Baconian school of philosophy, than to shew, that the labours of a few microscopic chemists, of men whose ideas might be supposed to be in a manner limited to the comparatively narrow field which their researches embraced, have done more towards the elucidation of one of the most abstruse questions on which the human mind can be engaged, than was effected by the profoundest intellects of

the ages that preceded them, furnished with all the learning of the times in which they flourished, and inured to habits of abstract and subtle disquisition :

To the members of an University like that to which I belong, consisting, as it does, of persons of whom the greater part may be presumed from their previous education to be conversant with ancient philosophy, whilst a few, it may be hoped, will have since imbibed something like a taste for modern science, it cannot be altogether uninteresting to consider the notions entertained by the most distinguished persons in the ancient, as well as the modern world, with respect to the constitution of matter ; nor will the view I propose to take of this subject be unimproving, if, without weakening that respect for antiquity which naturally flows from a converse with the great intellects of Greece and Rome, it adds one more proof of the benefits arising from experimental science, and of the unexpected advances in speculative knowledge that may often be traced to the investigation of a few apparently mean and insignificant details.

We cannot indeed extol too highly the vigour and grasp of intellect displayed by some of the philosophers of antiquity, which appear almost to

justify the glowing language which the Roman poet has applied to the Founder of the system he expounds, and to have indeed burst the barriers which Nature herself had imposed on human speculation :

*Ergo vivida vis animi pervicit, et extra
Processit longe flammantia moenia mundi.*

But we must at the same time recollect that these very barriers have receded before the march of discovery, and that whole provinces, into which the ancients only penetrated by a few desultory and random incursions, have been added to the domain of modern science—real and substantial possessions, which hold about the same relation to the visionary regions of knowledge existing in the imagination of the latter, as the lands explored by Columbus bear to the fabulous Atlantis.

Hence, unless we were to attribute a positive degeneracy to men of modern growth, an opinion, I conceive, which neither the condition of the arts nor the progress of civilization justifies us in entertaining, we should expect the views of nature presented to us at the present day to be more lofty and comprehensive than at any former period, in proportion to the greater extent of the field which our researches now embrace*.

* See in proof of this Humboldt's *Cosmos*, where the transcendental genius of ancient philosophy may be seen

Indeed, if the contrary opinion has at any time prevailed, the fault seems attributable, not so much to the condition of the sciences themselves, as to the teachers of them, who perhaps are often too sparing in those general inferences which the facts themselves are calculated to suggest; inferences which, though in all cases more or less conjectural, have their use nevertheless in expanding the powers of the mind, and in imparting a livelier interest to the subject under consideration.

The disciplined understanding indeed may be more secure from error, if the details are presented to it perfectly divested of theory; but where the object of the instructor is to train the mind as well as to inform it, there is probably as much gained by inculcating correct habits of generalization, as by storing the memory with the particulars which are to be employed as the basis of our reasoning.

Should such be the case, the present Essay may in some measure supply a deficiency that exists in the annual course of Lectures I am in the habit of delivering, as in the latter the press of matter obliges me to confine myself to a

combined with that extensive and exact knowledge of facts which ages of patient research have bequeathed as an inheritance to the moderns.

bare statement of what has been ascertained with regard to the laws of combination, without touching upon those speculative opinions respecting the constitution of matter, which, as it appears to me, have been so remarkably confirmed by the progress of modern discovery.

Two opinions on this subject have divided the ancient as well as the modern world ; the first, that matter is composed of an assemblage of particles incapable of farther division ; the second, that there is no limit to its divisibility, the smallest conceivable body still consisting of an infinity of parts.

For an exposition of the former doctrine we commonly appeal to the writings of the Epicureans ; but the notion itself may be traced much farther back. It formed indeed the groundwork of the cosmogony of Democritus, and was by him derived from Leucippus, who is generally reputed to be its author.

It is however stated, that the same opinion was held by Moschus, a Phœnician, whom some suppose to have flourished before the Trojan war, and if, as has been imagined, the monads of Pythagoras were corpuscular atoms, the Egyptians, from whom that philosopher derived so many of

his tenets, may probably have a claim also to this*.

It has been likewise shewn by Mr. Colebrooke†, that the Hindoos from a very early period embraced the doctrine of atoms, although the actual date of the system of philosophy into which this opinion enters is not fully made out.

According to Kanadi, the author whom he quotes, atoms constitute the last term of the division to which matter can be subjected. They are too small to be objects of sensation, for the particles of dust that are seen in a sunbeam, which are the most minute of visible things, are composed of several of them. They are simple and not compounded, otherwise the series would be endless, and were it pursued indefinitely, there would then be no difference of magnitude between a mustard seed and a mountain, a gnat and an elephant, each alike containing an infinity of particles. The ultimate atom therefore is simple. The first compound consists of two atoms,

* This seems confirmed by a passage in Aristotle's *Metaphysics*, in which it is said that Pythagoras considered his monads as possessed of size; τὰς μονάδας ὑπολαμβάνουσι ἔχειν μέγεθος. lib. xii. c. 6. Stobæus however says, that Ecphantus was the first who regarded the Pythagorean monads as corporeal. *Eclog. physica*, lib. i. c. 3.

† Asiatic Researches for 1824.

and the next of three double atoms; for if only two were conjoined, magnitude could hardly ensue from their union, since the latter must be produced either by the size or the number of the particles: it cannot be by their size, and must therefore be by their number. The atom, then, is laid down to be the sixth part of the mote which we see in the sunbeam.

Such was the doctrine that appears to have been most current among the Hindoo philosophers; but Mr. Colebrooke informs us, in another memoir, that it was objected to by the orthodox, some of whom, who professed to found their opinions on the text of the Indian scriptures, even argued against the existence of a material world, as was the case with certain philosophers in Greece who rejected the atomic theory, with Berkêley in England, and with the more modern school of natural philosophy hardly yet extinct in Germany.

Nor is it surprising that notions, which have stood their ground till the present advanced state of science, should have been broached at so early a period: as the first poets are pregnant with the grandest conceptions, so the earliest philosophers often light upon the most sublime truths; astonishing us with an intermixture of the noblest

views of nature with the most crude and vulgar conceits, and often leaving to their successors little more than the task of selecting from the mass of error the grains of truth which are disguised by and confounded with it.

Thus in the writings of Lucretius, we are struck in one page by the philosophical spirit which seems to anticipate the discoveries of modern times, in propounding a system not very different from the doctrine of *latent heat**, and maintaining, in opposition to Democritus, that the descent of heavy and light bodies *in vacuo* is equally rapid†; and in the next are provoked at the puerile manner in which the poet attempts to account for the independence of the Will, by imagining an occasional deviation from a straight line to take place spontaneously in some of his atoms, whilst descending through space.

It is the same with that part of his system which relates to the formation of the material world; we shall see reason perhaps to consider the position, that all bodies are composed of a certain number of ultimate particles, more consistent than any other with the discoveries of the present day; but we are not therefore the less sensible of the absurdity of supposing the beautiful

* Lib. i. v. 901.

† Lib. ii. v. 238.

variety of nature to be the result of a fortuitous concourse of insentient atoms, differing from each other solely in the mechanical properties of size, figure, and weight.

The doctrine itself is not the less probable because it fails to account for every thing which some of its supporters pretended to deduce from it, neither has it any natural tendency to atheism, although adopted by a sect of philosophers, who fancied they could dispense in their systems with the intervention of a Deity.

Nor do the original atomic theories appear to have been atheistical; on the contrary, the same philosophers, who proposed this view of the subject, considered matter, we are told, as wholly passive, and therefore admitted, as a necessary consequence, the existence of a moving principle which should be distinct from matter.

This, by some of the school of Thales, was pushed even to the opposite extreme of pantheism; for we are told that even the effects of magnetism, and other motions of inorganic substances, were attributed to an animated principle. Thales, says Aristotle, seems to suppose any thing productive of motion to be sentient, for he said that a stone possessed a soul because it moved iron*.

* "Εοικε δὲ Θάλης κινητικόν τι τὴν ψυχὴν ὑπολαμβάνειν, εἴπερ τὸν λίθον ἔφη ψυχὴν ἔχειν, ὅτι τὸν σίδηρον κίνει. Aristotle de

Indeed, as Cudworth has observed, there is a natural alliance between the atomic system and theology; the distinct notion which it conveys of the attributes of matter clearing the way to a more easy demonstration of incorporeal existencies, by convincing us that there are phenomena not referable to material causes, and therefore not explicable by the corpuscular hypothesis.

We may trace, however, several steps in the progress of development, from the theory of atoms, as first propounded by Leucippus, to the more mature form into which it was afterwards moulded by Epicurus.

Leucippus indeed appears to have accounted for the formation of the universe by a difference merely in the magnitude and figure of his atoms.

Owing to the former, there would be, he conceived, an agglomeration of the bulkier particles around certain centres; owing to the latter cause

Anima, lib. i. c. 2. Was not this the doctrine of Parmenides? See Sydenham, Dissert. on the Doctrine of Heraclitus, prefixed to his translation of Plato. If indeed all motion arises from a principle of vitality inherent in and pervading matter, and if this living principle be identical with the Soul of the universe, or God, then it will follow that all the varied phenomena of nature are manifestations of one and the same essence.

an entanglement of them, and a consequent cohesion of the particles thus brought together.

Round these central nuclei the smaller atoms would by degrees cluster, and in this manner an aggregation of matter in hollow spheres would first be brought about.

These latter, which he likens to bladders, would gradually contract in their dimensions, owing to the whirling motion (*δίνη*) impressed upon them by the collision of the particles flowing in from without, and thus would gradually be formed the various celestial bodies, including the sun, moon, and earth; the latter occupying the centre of the system, the sun and moon moving round it in cycles of greater or lesser extent.

In like manner the several bodies which compose each of these spherical masses would by degrees be produced, owing to the same whirling motion which had been impressed upon the particles, and to the tendency of like things when brought into contact to coalesce.

In what manner this whirling motion had its first beginning does not appear to have been clearly defined, and it was probably to supply this *desideratum* that Democritus, who imparted to the Atomic Theory greater prominence, and moulded it into a more consistent form, imagined a certain

inherent principle of vitality to exist in some of his atoms, from whence the movement originated, which might extend itself to the inert forms of matter intermixed.

It was this deviation from the simple doctrine of Leucippus, which Lucretius in the following lines condemns :

Illud in his rebus nequaquam sumere possis,
Democriti quod sancta viri sententia ponit ;
Corporis atque animi primordia singula, privis
Adposita, alternis variare, ac nectere, membra.
Nam quom multo sunt animai élémēta minora,
Quam quibus et corpus nobis, et viscéra constant ;
Tum numero quoque concedunt, et rara per artus
Dissita sunt ; dumtaxat ut hoc promittere possis,
Quantula prima queant, nobis injecta, ciere
Corpora sensiferos motus in corpore, tanta
Intervalla tenére exordia prima animai.

The theory, however, which has been commonly received in modern days, under the name of the Atomic Philosophy, is that contained in the writings which profess to unfold to us the doctrines of Epicurus, and especially in the verses of the sublimest of Roman poets.

It was Epicurus, who, discarding every other supposition except that of the existence of insentient atoms and a vacuum, and refusing to admit of any cause like intelligence, either external or

internal, which should originate motion, felt himself constrained to assign, in addition to figure and extension, a share in the formation of the universe to another of the properties of his atoms, namely to their weight.

Not indeed that Democritus, as Dumas represents*, denied to them gravity, but that he aimed at explaining the phenomena by mere differences in their magnitude and figure, without any reference to this property, which Epicurus principally appealed to.

It was this latter philosopher also who suggested, as a cause of that collision between the atoms of bodies to which he attributed their cohesion, some slight deviation from a straight line in the direction of the particles of matter, at uncertain times, and with unequal degrees of force.

Of this theory, however, as Dr. Good in his *Book of Nature* has given a sketch sufficiently clear and detailed for the limits of the present Essay, I shall in this instance spare myself the trouble of adding any thing of my own, and shall merely insert the substance of that which he has offered on the subject.

“The atomic philosophy of Epicurus,” says

* Sur la Philosophie Chymique.

Dr. Good, p. 61, "in its mere physical contemplation, allows of nothing but matter and space, which are equally infinite and unbounded, which have equally existed from all eternity, and from different combinations of which every visible form is created. Anterior to the formation of the universe, space and matter existed uncombined, or in their pure, elementary state. Space, in its elementary state, is absolute and perfect void; matter, in its elementary state, consists of inconceivably minute seeds or atoms, so small that the corpuscles of vapour, light, and heat are compounds of them; and so solid, that they cannot possibly be broken or abraded by any concussion or violence whatever. The express figure of these primary atoms is various; there are round, square, pointed, jagged, as well as many other shapes. These shapes, however, are not infinitely diversified; but the atoms themselves of each existing shape are infinite or innumerable. Every atom is possessed of certain intrinsic powers of motion. Under the old school of Democritus, the perpetual motions hence produced were of two kinds; a descending motion, from the natural gravity of the atoms, and a rebounding motion, from collision or mutual clash. Besides these two motions, Epicurus supposed that some atoms were occa-

sionally possessed of a third, by which, in some very small degree, they descended in an oblique or curvilinear direction, deviating from the common and right line anomalously.

These infinite groups of atoms, flying through all time and space in different directions, and under different laws, have interchangeably tried and exhibited every possible mode of rencounter ; sometimes repelled from each other by concussion, and sometimes adhering to each other from their own jagged or pointed construction, and from the casual interstices which two or more connected atoms must produce, and which may be just adapted to those of other figures, as globular, oval, or square.

Hence the origin of compound or visible bodies ; hence the origin of large masses of matter ; hence, eventually, the origin of the world itself. When these primary atoms are closely compacted, and but little vacuity lies between, they produce solids, such as stones and metals ; when they are loose and disjoined, bodies of lax texture, as wood, water, and vapour.

The world, thus generated, is perpetually sustained by the application of fresh tides of elementary atoms, flying with inconceivable rapidity through infinite space, and occupying the posts of

those that are as perpetually flying off. Yet nothing is eternal or immutable but these elementary atoms themselves. The compound forms of matter are perpetually decomposing and dissolving into their original corpuscles; to this there is no exception, minerals, vegetables, and animals, in this respect all alike, and new combinations proceeding continually from the matter into which they dissolve.

But the world itself is a compound though not an organized being; sustained and nourished, like organized beings, from the material pabulum that floats through the void of infinity. The world itself must therefore in the same manner perish; it had a beginning, and it will have an end. Its present crisis will be decomposed; it will return to its original, its elementary atoms, and new worlds will arise from its destruction.

Space is infinite, material atoms are infinite, but the world is not infinite. This, then, is not the only world, nor the only material system that exists. The cause that has produced this visible system is competent to produce others; it has been acting perpetually from all eternity; and there are other worlds, and other systems of worlds, existing around us."

This doctrine, of matter consisting of an assemblage of indivisible particles, seems to have kept its ground during the most flourishing periods of Greek philosophy under various modifications, the idea of one elementary matter deriving its form and properties from the shape and union of the particles composing it, being a simplification of the original hypothesis of Anaxagoras, who imagined distinct particles for each distinct substance, contending that every body in nature is maintained, not by the assimilation to its own texture of that from which it derived nourishment, but by the introduction into its system of new particles of the same nature with those whose waste they were to supply *. This may account for the

* Some approximation to this ancient theory is to be traced in the new views of Liebig and others, with respect to the building up of animal structures from proximate principles, received into the system from the vegetable kingdom, and but little modified afterwards. Anaxagoras in another particular seems to have anticipated the notions of the moderns, for he maintained that air comprised the elements of all beings whatsoever, and that these elements introduced by means of water generated plants.—Theoph. Hist. Pl. 3. c. 2. Diog. Laert. 2. §. 9. Compare this with the views so eloquently set forth in Dumas' *Statique Chimique*, commencing with the passage in page 6: "Les plantes et les animaux viennent donc de l'air et y retournent donc; ce sont de véritables dépendances de l'atmosphère."

statement of Plutarch, that Anaxagoras maintained all the phenomena of nature to have been produced by the Divine Mind at one and the same time; for though the individual objects of sensation may be undergoing a continual change and renewal, still, according to his system, the parts of which they are made up would have existed from the beginning of time, ready at any moment to start into being, forming, according to their respective natures, aggregates of bone, muscle, blood, as well as of stone, water, or air, which would possess collectively precisely the same qualities as their constituent particles :

Ossa videlicet e pauxillis atque minutis
Ossibus, sic et de pauxillis atque minutis
Visceribus viscus, gigni, sanguenque creari
Sanguinis inter se multis coëuntibus guttis.
Ex auræque putat micis consistere posse
Auram, et de terris terram condescere parvis;
Ignibus ex ignes, humorem humoribus esse;
Cætera consimili fingit ratione, putatque.

The conditions however of his system relieved him from the same necessity to which Epicurus was reduced, of supposing his particles indivisible; for as the minutest conceivable portions of each substance would possess precisely the same properties as the *whole*, the size and shape of the component parts could not affect the nature of

the aggregate arising from them ; whereas Epicurus, imagining these properties to have arisen from the very figure and magnitude of the particles, was obliged to assume that the latter were invariable, in order to explain the unchangeableness of the laws of nature, and the continual production of the same bodies.

According to either of these systems therefore only one kind of elementary matter was supposed, the different properties which distinguish bodies being in the one case supposed to emanate from the mechanical differences in their atoms, and the various arrangements of them arising out of these primary distinctions ; whilst in the other the properties in question were imagined to have been stamped by the *fiat* of the Almighty upon different portions of this first matter, so that the aggregates afterwards produced were nothing more than magnified representations of the qualities equally inherent in the minutest conceivable part.

Both these systems therefore may be considered as opposed to that of the Pythagoreans ; at least if we suppose the doctrines of that school to have been represented by the philosopher of Agrigentum, whom Lucretius extols in language of such high panegyric.

Quorum Agrigentinus imprimis Empedocles est,
 Insula quem triquetris terrarum gessit in oris

* * * * *

Quæ quom magna modis multis miranda videtur
 Gentibus humanis regio, visundaque fertur,
 Rebis opima bonis, multa munita virum vi:
 Nil tamen hoc habuisse viro præclarius in se
 Nec sanctum magis, et mirum, carumque, videtur.
 Carmina quin etiam divini pectoris ejus
 Vociferantur, et exponunt præclara reperta;
 Ut vix humana videatur stirpe creatus.

He, it seems, contended for the infinite divisibility of matter, and not admitting a vacuum, accounted for motion by maintaining that matter was created soft and pliable.

He it was who propounded, or at least invited attention to, the theory of all matter being resolvable into four elements, those of earth, air, fire, and water, by the intermixture of which in various proportions he supposed all other substances to be generated.

Still however his system had this in common with the prevailing philosophy of our own times—namely, that the bodies he called *Elements* were not regarded by him, as they have been subsequently by those who professed to adopt his views, primarily distinct in their natures—he imagining them all to be modifications of the same *First Matter*—we knowing at least that

they are compounds, and therefore not being precluded from entertaining any similar conjecture respecting their possible formation.

It would thus appear, that those varieties in the objects of nature, which according to Anaxagoras arose from similar variations in the properties originally impressed on the particles of matter by the hand of the Deity, and which according to Democritus emanated from the various combinations of atoms, in substance the same, but in shape and size different, were accounted for by Empedocles in a manner more consistent with the popular opinions at least, if not with the philosophy, of the present day, by four different kinds of matter variously mingled and combined.

It must however be added, that many who professed to follow his tenets, not only imagined that these elements were successively produced by a gradual condensation of the matter from which they all proceeded—the rarer elements being generated first, the heavier last in order, (according to a process which some astronomers have imagined to be taking place at present in the matter composing comets, and the bodies of which nebulae consist;) but even admitted the possibility of their mutual conversion at any subsequent period, thereby doing away with the very idea of an

element in the modern sense of the term, and leading us to imagine, that they regarded them rather as representing the four possible states in which matter can exist, corresponding to the solid, liquid, gaseous, and igneous conditions recognised in modern times, than as essentially distinct. Thus Ovid :—

Hæc quoque non perstant, quæ nos elementa vocamus ;
Quasque vices peragant, animos adhibete, docebo.
Quatuor æternus genitalia corpora mundus
Continet ; ex illis duo sunt onerosa, suoque
Pondere in inferius, tellus atque unda, feruntur :
Et totidem gravitate carent, nulloque premente
Alta petunt, ær, atque ære purior ignis.
Quæ quanquam spatio distant, tamen omnia fiunt
Ex ipsis, et in ipsa cadunt ; resolutaque tellus
In liquidas rorescit aquas : tenuatus in auras
Æraque humor abit : demto quoque pondere, rursus
In superos ær tenuissimus emicat ignes ;
Inde retro redeunt, idemque retextitur ordo. *Met.* XV. 237.

Empedocles seems also in another point of view to approach more nearly to modern ideas than most of his contemporaries, in accounting for the combinations amongst his elements by two powers which he called Love and Discord, or in modern scientific language, Affinity and Repulsion, instead of supposing them to arise from purely mechanical causes, as has been done by other philosophers both in ancient and modern times.

Indeed it is remarkable, that the most primitive philosophy of any with which we are acquainted, that philosophy which the most distinguished of the Greeks borrowed from, too often without acknowledgment, from which Plato adopted his *Ideas*, and Aristotle his *First Matter*, affords, even in the imperfect and disguised condition in which it has come down to us, a nearer approximation to the principles of modern science than the doctrines of the Grecian schools that succeeded it; as if, according to the conjecture of some writers, there really had existed amongst the priests of Egypt, or in more eastern climes, although carefully concealed from the vulgar, an insight into the mysteries of nature such as almost rivalled that of the present day, but of which lore a few scattered fragments only have been preserved by the blind reverence of the periods succeeding, when all knowledge had been lost of their purport, or of the relation they might have borne to the scientific structure of which they constituted a part.

That such a suspicion is not altogether without foundation, will perhaps be shewn in a subsequent part of this Essay, where I shall have to speak of the Pythagorean doctrine of numbers: at present it will be more to our purpose to consider the

influence which the dogmas of this school would exert upon the opinions they might entertain with regard to the infinite divisibility of matter.

It may be remarked in general, that whilst the existence of particles incapable of further division formed a necessary condition in the scheme of those, who, like Democritus and Epicurus, accounted for the properties of bodies on principles purely mechanical, so the opposite doctrine seems to have been in general adopted by such as took different views of natural phenomena.

It was reasonable, however, to expect, that greater importance would be attached to this question by the former class of theorists, than by the latter; with the one it constituted, as it were, the key-stone of their scientific edifice, with the other it was a problem of very subordinate interest; and accordingly, whilst the disciples of Epicurus employ all their talent and ingenuity in inventing arguments in favour of the doctrine of atoms, we find it somewhat difficult to collect the opinions of philosophers of other schools on this point, until indeed the prevalence of the Epicurean system made it worth the while of its impugnors to level an attack at the doctrine of atoms, as a means of demolishing the fabric built upon their assumption.

Thus Plato accounted for the origin of things by supposing two principles to have existed from all eternity, viz. Ideas and Matter; by the first of which he intended to express the conception of those general laws by which the course of nature is at present regulated, the models as it were of those properties by which bodies are characterized; and by the latter, a crude amorphous matter destitute in itself of all qualities, but capable of retaining any that might be impressed upon it.

The former must have existed from the beginning of time in the Divine Mind, because, although the phenomena of nature may vary, the principles on which these phenomena depend are fixed and invariable, and the material on which these properties have been impressed must have been in itself destitute of them, because, as in preparing a perfume, we are obliged to choose as a basis some ointment which is destitute of any odour of its own, and as in moulding a statue we ought to select a material capable of retaining any form, but from which we can completely efface that which it may happen at the time to possess; so the Divine Artificer would have stamped the images of those eternal ideas which emanated from his own intelligence, upon a something which was

entirely destitute of all form and characters of its own.

Satisfied apparently with accounting by these sublime abstractions for the qualities of bodies in general, and thus reconciling the fluctuation of external objects with the immutability of the Divine Mind, Plato seems to have troubled himself little about the mode in which the subordinate varieties of matter might have arisen from its great primary distinctions; and though he sometimes amused himself with those mechanical speculations which engrossed the attention of the corpuscular philosophers, yet he evidently attached but little importance to such inquiries. ~

Thus he, on the one hand, appears to contend for the infinite divisibility of matter, whilst on the other he adopts the Pythagorean doctrine of four elements deriving their characteristic distinctions, in some measure at least, from the shape of their component particles. Those of fire he supposes to be a four-sided pyramid; those of air an octaedron; those of water an icsaедron; those of earth a cube; and he further accounts for the mutual convertibility of the three former elements one into the other, by the mathematical relation between the figures of their molecules; a four-sided pyramid being composed of four equilateral

triangles, an octaedron of eight, and an icosaedron of twenty.

Earth, on the contrary, consists of particles, whose figure being a cube bears no mathematical relation to that of the three former, and hence this element is not convertible into the rest*.

The doctrines of Aristotle on these points appear to have approached to those of Plato, except that he equally rejected the Platonic doctrine of Ideas and the Pythagorean one of Numbers.

He admits a *substratum* bearing the same relation to all the productions of nature, which iron does to the saw, or marble to the statue fabricated out of it, so completely denuded of properties, that we scarcely know how to admit its materiality, but receiving from the hand of God the various qualities it possesses, as the iron and the marble in the cases above mentioned acquire their forms from the artificer.

He does not allow of the four elements of Empedocles, because the substances called such by that philosopher are convertible one into the other; but he agrees that they represent the four primary affections of matter perceived by our

* Plato in *Timæo*.

senses, of hot, cold, dry, and moist, into which all others appear to be resolvable*.

In addition to a *substratum* capable of receiving the properties impressed upon it, and *form*, by which its existence becomes cognisable to our senses, Aristotle adopts as one of his first principles, *privation*, or the absence of matter, which seems to correspond with the Epicurean vacuum; to these, however, he adds (*νοῦς*) *intelligence*, as the original and directing cause of the whole; improving in this respect upon the doctrines of the corpuscular philosophers of his time, all of whom, however they might shift their ground from one supposition to another, imagined, in the last resort, motion without a mover, and causation without a cause.

With regard to atoms, he contends against the arguments of Democritus on this subject; but admits that matter may be made up of particles which are actually, though not potentially, indivisible.

Ἐν τῷ συνέχει, he observes, ἔνεστι μὲν ἄπειρα ἡμίση, ἀλλ' οὐκ ἐντελεχεία, ἀλλὰ δυνάμει.

* So Milton:—

For hot, cold, moist, and dry, four champions fierce,
Strive here for mast'ry, and to battle bring
Their embryon atoms.

The above brief outline of the dogmas entertained by the philosophers of antiquity on the constitution of matter, may be sufficient to convince us how complete a division of opinion existed on the subject; and if, without heeding the authority of names, we regard only the arguments alleged in support of either side, we shall find perhaps an equal difficulty in arriving at any decision.

The advocates of the doctrine of ultimate atoms contended, that without such an arrangement there would be no permanency in the existing system of things; that the particles of which matter is composed, worn down more and more during a period of indefinite extent, would have been by this time unable to form any thing possessing bulk and solidity; or else would produce substances of a very different kind from what they gave rise to formerly, when in a less comminuted condition.

They argued, that as every thing in nature which comes under our observation possesses a definite size, or at least one circumscribed within certain boundaries, so also must the parts of which these substances themselves consist.

They contended, that the races of animals, and

the tribes of plants, could not have preserved their uniformity for so long a period, if the particles out of which they were formed had undergone any change in size and figure; for from these primary qualities arose, according to the Epicurean doctrine, all the characteristic peculiarities by which we recognise one substance as distinct from another.

The arguments alleged in proof of the infinite divisibility of matter appear in general, so far as I can understand them, to be rather of a metaphysical than a physical nature.

By Leibnitz the existence of atoms was opposed, as inconsistent with two of his leading dogmas;—the law of Continuity, and the doctrine of a Sufficient Reason.

The very notion of an atom, he contends, implies that of absolute hardness; now if two bodies perfectly hard, and therefore altogether inelastic, were to meet with equal and opposite motions, they must both necessarily stop at once. Hence to suppose the existence of bodies so constituted as to pass instantly from a state of rapid movement to one of perfect quiescence, is inconsistent with the law of Continuity, which implies that no

change can take place abruptly, or without passing through the intermediate gradations of motion slowly subsiding into rest.

The existence of atoms he considered also to militate against the doctrine of Sufficient Reason ; but what he here remarks would scarcely be comprehended without such a previous sketch of his almost forgotten opinions on this subject, as would be out of place in the present Essay.

More intelligible are the arguments advanced against the doctrine of atoms by the Cartesians, although those philosophers likewise confined themselves to the "*high priori road*," and contented themselves for the most part with proving, that no body can be considered in a mathematical sense incapable of division.

Of such a description indeed are the remarks of cardinal Polignac in his *Anti-Lucretius* *, except where his attacks are directed against those particular tenets of the Epicureans, respecting the angular shapes of their particles, in which, I conceive, the atomic philosophers of the present day do not feel it necessary to concur.

Keill, in his *Lectiones Physicæ*, read before this

* See also Grandis Instit. phil. secundum Principia R. Descartis part. iv. c. 3.

university, has stated the mathematical objections at considerable length, and appears to have sufficiently demonstrated that no substance can be conceived so minute, as not to be still further divisible. So long, he contends, as you allow to the particles of matter extension, you must admit them to consist of parts; and whatever consists of parts must be set down as capable of division. And it was doubtless to evade an argument of this kind, that Zeno, amongst the ancients, contended that matter was made up of a number of points not possessed of extension, an hypothesis with which the doctrine of monads entertained by Leibnitz seems pretty nearly to agree.

In either case, however, the difficulty meets us, of imagining the property of extension to belong to a body taken collectively, when the same is not predicated of its component parts: and it was to reconcile this apparent inconsistency that the Abbé Boscovich, who may be considered a disciple of Leibnitz, as well as an improver upon the system of his master, framed his theory of the Constitution of Matter*.

He supposes, in common with the philosophers above alluded to, that matter is made up of a

* *Philosophiæ Naturalis Theoria*, Viennæ, 1759.

number of unextended, indivisible points, which, however, never touch each other, owing to the mutual repulsion subsisting between them, so soon as they come within a certain distance of each other; which repulsion increasing gradually in proportion as they are made to approach nearer and nearer, becomes at length too powerful for any force to overcome.

This theory agrees with the fact that there is no such thing in nature as absolute contact; and the impenetrability of matter, which gives us the first idea of extension, is, according to Boscovich, nothing more than the resistance opposed by the physical points of which matter consists to the approach of another body within a certain distance of itself.

Thus he supposes that the points of matter alternately attract and repel each other, according to the distance that separates them, until they either come very close to, or are removed to a comparatively great distance from each other: in the former case they are repelled, in the latter attracted; the former force preventing mutual contact, the latter, which, when considered as acting between the earth and bodies upon it, is no other than gravitation, drawing them all together.

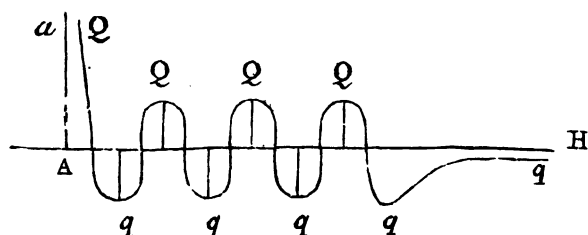
He instances two particles combined in the form of water. These have, first, the repulsion which produces impenetrability; secondly, at an increased distance, the attraction which causes aggregation. Now if by some cause, such as heat, the second particle be removed to a greater distance, (still within insensible limits,) so that the water is converted into vapour, at this third distance repulsion acts, producing elasticity; but to this also there are certain limits; for the particles cannot be separated (that is, the aeriform nature or repulsion between them increased) beyond a certain point, where it is overcome by attraction; or, in other words, we have a fourth distance, where attraction acts, and beyond which it prevails *ad infinitum*.

This law he expresses by an equation which is represented geometrically by a curve intersecting a straight line in certain places. The ordinates of the curve represent the attracting and repelling forces of two particles; the one supposed to be stationary at the point *A*, the other placed at successive distances along the straight line towards *H*.

The ordinates of the curve, when above the straight line, indicate repulsion: when below it, attraction.

The points of greatest attraction and repulsion will therefore be those in the axis corresponding to those in the curve marked by the letters $Q Q Q Q$ and $q q q q$ respectively; and it is seen that when the particle reaches such a point, the contrary force begins to operate; and that where the curve intersects the straight line, the forces of repulsion and of attraction are in equilibrio.

Now these points are termed by Boscovich the limits of cohesion, because particles placed on those points remain unaltered in their position.



The line of the axis $A H$, and that of the perpendicular $A a$ being both asymptotes to the curve $Q Q Q Q q q q q$, corresponds to the condition that the repulsion at a and the attraction at H is infinitely great; hence a particle impelled by any force from H towards another at A , can never come into perfect contact with it, neither if driven from it can it recede to an unlimited dis-

tance, owing to the constantly operating force of attraction.

The learned Dr. Good, in his *Book of Nature*, remarks, that the difficulties chargeable upon the doctrine of an infinite divisibility of matter are not touched by this theory of Boscovich's, but remain in as full force as before it. "If," says he, "the monads, or ultimate points of matter here adverted to, possess body, they must be as capable of extension, and consequently of division, as material body under any other dimension or modification: if they do not possess body, then they are as much nonentities as the primal or amorphous matter of Plato or Aristotle. Again, we are told that these points or monads are endowed with certain powers, as those, for example, of attraction and repulsion. But powers must be the powers of something; what is this something to which these powers are said thus to appertain? If the ultimate unextended points before us have nothing but these powers, and *be* nothing but these powers, then are such powers powers of nothing, powers without a substratum, and consequently, as much nonentities as in the preceding argument. Visible or sensible matter, moreover, it is admitted by Boscovich and his disciples, is possessed of extension; but visible or sensible

matter is also admitted to be a mere result of a combination of unextended atoms ;—how can extension proceed from what is unextended? of two diametrical opposites, how is it possible that either can become the product of the other?"

I confess I do not see the case in quite the same light as Dr. Good ; for it seems to me that the merit of Boscovich's system consists in explaining, as far as such a subject admits of being explained, in what manner the idea of extension may arise, from the resistance offered by a number of physical points of matter to the approach of a foreign body, thus shewing that the possession of dimensions, as of breadth, length, and thickness, and consequently of parts, which we imagine to be implied in the very definition of extensibility, is not altogether inseparable from it.

Dr. Good therefore, it may be observed, takes for granted the point required to be proved, namely, that because matter in every shape in which it comes before us possesses extensibility, and consequently parts, therefore that the units composing it do the same. Now it was the very object of Boscovich's treatise to explain, that even the idea of extension may resolve itself into something more simple, namely, into resistance to external pressure, and that physical points even, if

endowed with powers of attraction and repulsion, might exclude foreign bodies from a portion of space, and thereby produce impenetrability—a property from which, considered under different aspects, result the notions of substance, figure, and bulk.

Yet though the ingenuity of Boscovich may have invented a theory that allows us to maintain in argument the doctrine of particles mathematically indivisible, without enabling our antagonist to convict us of an absurdity, it can hardly persuade any one of their reality, nor am I disposed to disagree with Dr. Good in his concluding sentences, in which he remarks, that the “lesson taught us by all such fine-spun and fanciful hypotheses is, the impossibility of philosophizing without a basis of first principles, without the establishment of certain postulates to be taken for granted in all the subsequent discussions.”

“We must have them in physics as well as metaphysics, in matter as well as in morals; and hence the best physical schools in Greece, as well as in more modern times, have found it necessary to take it for granted—what in fact can never be absolutely demonstrated—that matter in its ultimate parts consists of solid, impenetrable, and movable particles of definite sizes, figures, and

proportions to space; from different combinations of which, though invisible in themselves, every visible substance is produced *."

Ingenious indeed as the theory of Boscovich may be, and skilfully as it seems to evade the difficulties that beset us so soon as we attempt to assign limits to the divisibility of matter, the mass of mankind will be glad to escape from such obscure and abstract speculations, by waving entirely the mathematical question, and confining themselves simply to the inquiry, whether it be not most consistent with sound philosophy to admit in a physical sense the existence of atoms; that is, of bodies, not destitute indeed of parts, but having those parts held together by a force

* It is curious that Dr. Priestley, the coryphæus, as he may be termed, of materialism, has, in attempting to shew that mind is not spiritual, been led by the tenor of his argument to push Boscovich's doctrine so far, as almost to deny the materiality of body; for he contends that we have no proof of substance being any thing more than powers of attraction and repulsion, thus denying to it solidity, impenetrability, and the like. "Since matter," he concludes, "has in fact no properties but those of attraction and repulsion, it ought to rise in our esteem; as making a nearer approach to the nature of spiritual and immaterial beings, as we are tempted to call those who are opposed to gross matter." See Priestley on Matter and Spirit, p. 37, and History of Discoveries relating to Vision, p. 454.

capable of resisting any natural means which can be brought to separate them.

By such a supposition, whilst we evade the objections already alleged against the theory of atoms, we at the same time may avail ourselves of the authority of even those Greek philosophers who were most opposed to the system of Epicurus, but who nevertheless found themselves obliged to adopt the idea of atoms, which, though potentially, were not actually divisible, as we see from the passage of Aristotle already quoted.

If the application of the term *atom* in such a sense be objected to, we may answer, that the same remark will apply with reference to the particles of an homogeneous body, as to the parts of one consisting of heterogeneous elements.

Supposing, for example, gold or iron to consist of several elementary matters, which yet had been bound together from the beginning of time by some attraction too strong for any earthly power to separate them, such substances, however composite, ought perhaps to be considered, *quoad nos*, elementary, since in their relation to ourselves, and to all the substances of which we have any experience, they act as elementary bodies would do.

In like manner, if we had reason to believe that there existed in nature bodies of whatever dimen-

sions, the parts of which were indissolubly united, they might, I conceive, without impropriety be denominated *atoms*, or at least be classed with such bodies.

Such probably was the meaning of Democritus, when he spoke of atoms of considerable weight and size; not that he would persuade us that such bodies were without parts, but that he considered the cohesion of the latter as too great to be overcome*.

The question therefore now before us resolves itself simply into this, whether there be any reason to conclude from the review of natural phenomena that the Deity has assigned a limit to the divisibility of matter? since, if such be the fact, we may fairly speak of and reason upon the ultimate particles to which the division can be car-

* Heraclides Ponticus (not Heraclitus, as Dr. Good by mistake has stated), and after him Aesclepiades of Bithynia, substituted in their system the term *ἄγκοι*, as more appropriate for masses of matter than the term *ἄτομοι* employed by Democritus; just as some chemists prefer the term *molecules* to *atoms*; but then, by a further deviation from the system as entertained by Epicurus, he supposed these particles not only to be incongruous (*ἀναρμοστοί*), but also liable to be broken and altered (*θραυστοὶ καὶ παθητοί*). Hence this latter doctrine cannot be appealed to on the present occasion. (See Sprengel's History of Medicine, vol. 2.)

ried as atoms, although they may be proved mathematically to consist of an infinite number of points.

Now this is the very view which has been taken, not only by the ancient philosophers already alluded to, but also by Newton, who in this particular adopts the principles of the Epicureans, and even supports them by arguments of the same description as those conveyed to us in the verses of the illustrious Roman poet.

“All things considered,” he says, “it seems
“probable, that God, in the beginning, formed
“matter in solid, massy, hard, impenetrable,
“moveable particles, of such sizes, figures, and
“with such other properties, and in such proportion to space, as most conduced to the end for
“which he formed them; and that these primitive
“particles, being solids, are incomparably harder
“than any porous bodies compounded of them;
“even so very hard as never to wear or break
“to pieces; no ordinary power being able to
“divide what God himself made one in the first
“creation.

“While the particles continue entire, they may
“compose bodies of one and the same nature and
“texture in all ages; but should they wear away,
“or break in pieces, the nature of things depending

“ on them would be changed *. Water and earth
“ composed of old worn particles would not be of
“ the same nature and texture now with water
“ and earth composed of entire particles at the
“ beginning. And therefore, that nature may be
“ lasting, the changes of corporeal things are to
“ be placed only in the various separations, and
“ new associations, and motions of these permanent

* Thus Lucretius :

Nam si primordia rerum
Commutari aliqua possent ratione revicta,
Incertum quoque jam constet, quid possit oriri,
Quid nequeat ; finita potestas denique quoique
Quanam sit ratione, atque alte terminus hærens :
Nec toties possent generatim sæcla referre
Naturam, motus, victum, moresque parentum.

And again,

Denique, si nullam finem natura parasset
Frangundis rebus, jam corpora material
Usque redacta forent, ævo frangente priore,
Ut nihil ex illis a certo tempore posset,
Conceptum, summum ætatis pervadere finem ;
Nam quidvis citius dissolvi posse videmus,
Quam rursus refici : quapropter longa diei
Infinita ætas anteacti temporis omnis,
Quod fregisset adhuc, disturbans dissoluensque,
Nunquam id reliquo reparari tempore possit :
At nunc nimirum frangundi reddita finis
Certa manet, quoniam refici rem quamque videmus,
Et finita simul generatim tempora rebus
Stare, quibus possint ævi contingere florem.

“ particles ; compound bodies being apt to break,
“ not in the midst of solid particles, but where
“ those particles are laid together, and touch in
“ a few points *.”

With respect to the refinements that it has since been attempted to introduce into this doctrine, as by Wolf in his *Monads*, which seem to partake of the properties both of *points* and of *atoms*, and by Swedenborg in his efforts to explain on mechanical principles, by the form and arrangement of the molecules, such chemical properties as serve to distinguish each respective body, I can only say, that those who adopt these subtleties appear to *me* to be abandoning that vantage ground which the atomic philosopher possesses over the rival theorist, so long as he contents himself with principles that can be clearly apprehended, and therefore may be readily grappled with.

Let it not however be supposed that the doctrine in question has become the universal creed amongst philosophers, since Newton gave it the sanction of his great name. Many no doubt would be swayed by the authority of Des Cartes and Leibnitz, who leaned to the opposite opinion ;

* Horsley's Newton, vol. ii. p. 260.

and even within a few years we find an eminent experimentalist, as well as a refined reasoner, such as Dr. Faraday, lending his support to views not very dissimilar to those of Boscovich.

Dr. Faraday* contends, that our hypothesis constrains us to attribute opposite and even contradictory properties to space, as in some cases that surrounding and intermingling with bodies tends to prevent the passage of electricity—in others, to allow its ready transmission.

I cannot however bring myself to assign any properties at all to mere space, and should conceive the transmission or retention of the electricity, or rather the relative quickness with which the fluid is conveyed from one body to another—for no body is a perfect insulator, as none is altogether destitute of all retarding influence upon its escape—to depend upon the nature of the substance and not upon that of the intervening space.

It is true, as Dr. Faraday well observes, that this and other affections of matter are not determined by the number of atoms grouped together, nor yet by their volume; but I shall attempt to shew in a subsequent chapter, that the properties which we designate as chemical, may all be sup-

* Phil. Magazine, vol. xxiv. 1844.

posed to be in some way connected with the arrangement of the component particles, so that the changes in this respect which take place, when one substance combines with another, or when the same is subjected to certain influences calculated to affect its arrangement, may be explained upon this supposition, as well as upon that which assumes an alteration in the forces imagined to be collected round certain centres.

Those who can bring themselves to admit the existence of forces without a something, to which these forces belong, and from which they emanate, may very possibly be able to explain the phenomena upon Dr. Faraday's principles: but my reasonings are addressed to that large body of chemists, as well as of unscientific men, in this country, who have hitherto recognised the existence of matter, invested with certain fundamental properties, as being a notion more intelligible at least, if not more philosophical, than the other.

In a case of this kind, however, much will depend upon the character of the mind, and the nature of the antecedent studies, of those who consider the question. Thus to many of the speculative reasoners of Germany, the Atomic Theory seems to have been unpalatable, perhaps for the very reason for which it had been disregarded in

the metaphysical schools of Greece, by whose disciples we find it stigmatized as crude and unphilosophical, for that which in the eyes of others appears one of its principal merits—namely for the very simplicity of its fundamental positions.

Kant and his followers preferred accordingly regarding matter as penetrable throughout, and as owing its present condition to the balance between the two forces of contraction and expansion. If the former alone existed, the whole universe would be reduced to a mere mathematical point; if the latter, it would spread itself equally over all space. But owing to the operation of the former power, matter is compressed to a certain limit, beyond which the opposite force operates with superior energy, and thereby prevents any further contraction.

When two kinds of matter shew an affinity one for the other, it is because they are actually penetrable, and when a perfect solution of one substance in another takes place, both are infinitely subdivided, so that each ingredient is uniformly diffused throughout the mass.

It must be confessed that this, which has been called the Dualist system, presents, even in the form in which I have here exhibited it, but an obscure and imperfect image to the mind; but

the more modern German schools of natural philosophy appear to have pushed their opinions much further, as they endeavoured to explain every thing by two forces, expansion and attraction, of which what we call Matter was the result.

This attempt at the complete annihilation of substance, this entire resolution of all the phenomena presented to the senses into the effects of forces, which are not yet admitted to belong to any *substratum*, seems as repugnant to our notions on the one side, as the attempt of Epicurus to explain every thing by the mechanical properties of his atoms is on the other; and few, I conceive, excepting those whose minds are in a manner preoccupied by the dogmas of this philosophy, which from metaphysics once strived to extend its empire into the domain of science, and even into that of natural history, will consider the theory in question established on sufficient evidence, to be regarded as an impediment to the reception of truths based upon the more substantial and palatable footing of experiment.

CHAPTER II.

Outline of the facts ascertained in modern times with respect to the combinations between bodies—Proportions in which they unite together are in general definite as to quantity, and limited in point of number—Wenzel's and Richter's researches on this subject—Opinions entertained by Mr. Higgins—Generalized view of the phenomena presented by Dalton, who established that every substance enters into combination in certain fixed proportions, of which the larger are multiples of the smallest—Whether these proportions are to be considered in all cases as multiples also of the combining proportion of hydrogen—Mechanical contrivance for facilitating the calculation of the quantity of any one body requisite to combine with a given quantity of another—What body ought to be assumed as unity—Exceptions to the law of multiples considered—Dr. Prout's opinion with respect to the doctrine of definite proportions—Gay-Lussac's theory of volumes—Relation existing between the volumes and the quantities of bodies which combine—And likewise between their combining proportions and their specific gravity.

Berzelius' canons with respect to chemical combination—Exceptions to their universal application.

HAVING in the preceding chapter reviewed the opinions of the most distinguished philoso-

phers anterior to the present age, with respect to the constitution of matter, and shewn how completely they failed in arriving at any conclusion calculated to command assent, I propose in the next place to consider the laws more recently determined with respect to the definite proportions in which bodies combine; after which we shall be better prepared to understand what degree of assistance has been derived towards the solution of this problem from modern experimental research.

Let it not, however, be imagined, that I mean to represent the value of the important discovery, of which I am about to offer a sketch, as though it were mainly dependent on its relation to an inquiry, which, like the one alluded to, is purely speculative; its practical importance, as we shall afterwards find, gives it a much higher claim; and we should dislodge the reputation of its inventor from the solid foundation on which it stands, if we were to attempt to rest it on the accidental circumstance of its having afforded an additional argument against the position, that matter is infinitely divisible.

All minds, nevertheless, are not cast in the same mould, and there may be some, who, from natural bias, or from habits acquired by educa-

tion, attach greater importance to the theoretical than to the practical results of a discovery; and who would therefore pay an attention to the doctrine of definite proportions from finding it throw light upon a question of speculative interest, which they might not bestow upon it from its relation to a science, with respect to the details of which they feel indifferent.

Nor will those even of a more practical turn of mind deny, that an additional triumph will have been reaped by modern science, if it can be shewn to have achieved, as it were incidentally, and on ground not its own, that which the philosophy regarded by us with a reverence at once so just and so natural left unaccomplished, and to have discovered a series of facts, which, granting that it be not absolutely decisive of the question alluded to, lends at least a much greater preponderance to the corpuscular theory over that opposed to it, than it had attained in any former period at which its pretensions were made the subject of discussion.

No sooner had modern chemistry advanced sufficiently in the art of manipulation, to allow of experiments being conducted with a frequent appeal to the balance, than what before could

only have been conjectured, or at most taken for granted without direct proof, became a matter of demonstration; the identity of composition belonging at all times to the same body, in whatever manner it may be produced, then becoming established by every trustworthy analysis.

It was shewn moreover, that if two ingredients are capable of uniting in more than one proportion, the nature of the substances produced by their union often bore no sort of relation one to the other, but belonged frequently to a distinct class of bodies. One of them, for instance, might possess acid properties, the other be tasteless and inert; or one might be combustible, whilst the other extinguished flame.

It could not fail too to be remarked, that in those cases in which the combining bodies had their chemical properties altogether effaced (without which indeed it may be doubted whether any true chemical union can take place) the number of combinations of which they were susceptible did not appear to be indefinite; that on the contrary there were few instances in which they exceeded four or five at the most; and that, when the ingredients were presented to each other in intermediate quantities, we did not usually find several distinct substances to result, but some one

definite compound to be formed, and a certain amount of the element which happened to be in excess to remain with its properties unaltered in the mixture.

The above principles being ascertained, it was natural that the relation, which the several compounds consisting of the same ingredients might bear one to the other, should be a subject of inquiry; and it is only surprising that men of science so long overlooked the simple law, by which such combinations between bodies are now shewn to be regulated.

The first step towards the determination of this point was made about sixty years ago by a German chemist named Wenzel, who, in a work entitled *Lehre von den Verwandschaften*, published at Dresden in 1777, shewed, by a series of analyses which are now admitted to be remarkably accurate, although they met with little attention at the time, that when two neutral salts decomposed each other, both the resulting compounds were exactly neutral. Thus, supposing sulphate of silver and nitrate of barytes to be brought into contact, two neutral salts, consisting of nitric acid and oxide of silver, and of sulphuric acid united with barytes, will result; and if to the nitrate of silver that had been formed phosphate of soda

were added, we should next obtain phosphate of silver and nitrate of soda, both alike neutral.

Thus let the quantities employed be, 19.7 grains of dry sulphate of silver, which consist of 5 grains of sulphuric acid and 14.7 of oxide of silver, and 16.5 grains of nitrate of barytes, which consist of 6.75 of nitric acid and 9.75 of baryta.

On mixing these substances we shall get 21.5 grains of nitrate of silver, consisting of 6.75 of nitric acid, and 14.75 of oxide of silver; together with 14.75 grains of sulphate of barytes, consisting of 5.00 grains of sulphuric acid, and 9.75 grains of barytes. Now it will be seen, that these are exactly the quantities of the several ingredients present in the two substances originally existing, which were destroyed by being brought into contact.

The changes that have thus taken place may be represented by the following diagram, if we adopt the method of expressing such phenomena which was introduced by Bergman, a chemist to whom we are indebted for much of our information on the subject of this class of decompositions.

Nitrate of Silver 21.5 grains.			
Sulphate of Silver 19.75. gr.	Oxide of Silver 14.75 grains.	Nitric Acid 6.75 grains	Nitrate of Barytes 16.5 grains
	Sulphuric Acid 5.00 grains.	Barytes 9.75 grains	
	Sulphate of Barytes 14.75 grains.		

According to this diagram, the substances to the right and left without the hyphens represent the ones brought into contact, and those above and below the straight lines the new bodies resulting from the play of their mutual affinities, the soluble compound formed being placed above, the insoluble one at bottom.

The quantities of each of these, and also of their component parts, are given in the diagram; so that we see at once what quantity of sulphuric acid will neutralize or destroy the properties of 14.75 grains of oxide of silver, and of 9.75 grains of barytes; and also what quantity of nitric acid will be required to neutralize an equal amount of the same bodies.

It follows, therefore, that 5 grains of sulphuric acid are equivalent to 6.75 of nitric acid, and *vice versa* 14.75 grains of oxide of silver to 9.75 of barytes.

By the same rule, when the 21.5 grains of nitrate of silver resulting from the above process are presented to 7.5 grains of dry phosphate of soda, the following changes take place:

Nitrate of Soda 10.75 grains.			
Nitrate of Silver 21.5 gr.	<div style="display: flex; justify-content: space-around;"> Nitric Acid 6.75 gr. Soda 4.0 gr. </div>		Phosphate of Soda 7.5 gr.
	<div style="display: flex; justify-content: space-around;"> Oxide of Silver 14.75 gr. Phosphoric Acid 3.5 gr. </div>		
	Phosphate of silver 18.25 gr.		

From the above facts therefore we infer, that 5.0 grains of sulphuric, 6.75 of nitric, and 3.5 of phosphoric acid, may be regarded as chemical equivalents; as may likewise, for the same reason, 4.0 grains of soda, 9.75 of barytes, and 14.75 of oxide of silver.

It was accordingly upon this principle, that Richter, a Prussian chemist, following in the footsteps of Wenzel, endeavoured to ascertain the relative capacities of saturation which belonged to the several acids and bases, and to express them by a scale of numbers*; thus rendering chemistry, which had in the first place been conversant merely with the *qualities* of matter, a science also of *quantity*; and providing it in a manner with a new instrument of research, from the moment that calculation was called in to check and correct the unavoidable errors of experiment.

The results of Richter's researches were published in a table, of which the following is an abridgment;

* In his work called *Anfangsgrunde der Stochiometrie*. Breslau, 1792; and in a periodical publication, entitled, *Über die neuen Gegenstände der Chemie*, which appeared at various intervals between the years 1792 and 1802.

Equivalent quantities of

Alumina.....	525	Carbonic acid ...	577
Magnesia	615	Muriatic	712
Ammonia	672	Oxalic	755
Lime	793	Phosphoric	979
Soda	859	Sulphuric	1000
Strontian	1329	Nitric	1405
Potass.....	1605	Acetic	1480
Barytes	2222	Tartaric	1694

Thus, for instance, it would appear from this table that 1000 grains of sulphuric acid saturate 525 grains of alumina, 615 ditto of magnesia, and such quantities of the other earths as are denoted by the number attached to each name; and in like manner that 2222 grains of barytes saturate 577 ditto of carbonic, 712 of muriatic acid, &c.

Two inquiries might have been suggested by the consideration of this table of Richter's; the one having for its object a mere amplification or extension of it, the other an investigation of an analogous kind.

It was in the first place to be determined, whether the same law, which had been pointed out with respect to a few of the acids and bases, held good generally throughout nature, and par-

ticularly whether it prevailed where two or more combinations between one body and another existed; and 2ndly, if this were the case, whether any relation could be traced between the quantities of those substances which entered into combination in more than one proportion.

Thus, for example, if in a salt known to consist of sulphuric acid and potass, the acid had been found to combine with the alkali in the proportion of 1000 to 1605, and a new compound consisting of the same ingredients were discovered; it might be inquired whether any relation existed between the number of 1605 respecting the quantity of potass present in the former salt, and that indicating the proportion in which the same alkali occurred in the compound afterwards recognised.

Now supposing the quantity of alkali in this latter case to have been estimated at 802.5, or exactly half the former number, the coincidence would scarcely have appeared to us as merely accidental; and if the same relation had been observed in a variety of analogous instances, we must then have been compelled to regard it as indicating a law of nature, and as produced by some cause operating generally throughout matter.

In the instance before us indeed the relation

between the two compounds of sulphuric acid with potass is not correctly expressed by the numbers given, for according to later experiments 1000 of sulphuric acid would be equivalent to 1200 of potass, instead of 1605, and consequently other existing combinations could not be expected to bear a numerical relation to this latter number.

Still however, on reviewing the subject with the lights of our present information, it seems rather remarkable, that an approximation at least to the real composition of some of the substances so related was not sooner obtained from the analyses that had been from time to time conducted, so that nearly thirty years were suffered to elapse, not only without any attempt to extend the law of Richter's to bodies more simple than those on which he had operated, but even without any idea having been entertained with respect to the proportion existing between the quantities of a substance which combines with another in more quantities than one.

It has been contended, that we owe to Mr. Higgins, formerly of Pembroke college in my own university, and afterwards Professor of Chemistry to the Dublin Society, the first enunciation of this

latter fact, as in a work published by him in 1789, entitled, "A Comparative View of the Phlogistic and Antiphlogistic Theories," he distinctly states, that one ultimate particle of sulphur and one of oxygen constitute sulphurous acid, whilst one ultimate particle of sulphur and two of oxygen constitute sulphuric acid; and moreover that in the compounds of azote and oxygen the ingredients are to each other in the proportion of 1 to 1, 2, 3, 4, 5, particles respectively.

It must also be allowed, that he adheres, throughout the work in question, to the corpuscular hypothesis, supposing matter to combine particle to particle, though in this latter respect the merit is not exclusively his own, as he merely followed in the wake of preceding chemists, who, if they thought at all upon the subject, generally leaned to the opinion that chemical combination took place between the ultimate molecules of matter, and not, according to the Kantian doctrine, owing to a mutual penetration of one substance by another.

But although the definite proportions in which bodies combine afford, as will be seen hereafter, the most satisfactory proof we possess of the existence of atoms, it must not be taken for granted, that the adoption of such a view necessarily pre-

supposes a recognition of the former principle, nor does it appear, that Mr. Higgins had a clear perception, that the several combining quantities of each substance bore any fixed numerical relation one to the other, or that he had brought together any facts in support of such a position.

Indeed it may be collected from other passages, that he supposed combinations between bodies to take place in all proportions within certain prescribed limits, a notion utterly inconsistent with any clear apprehension of the principle in question.

Had he struck out these ideas a few years later, the case might have been different; for as their correctness could then have been substantiated by an appeal to facts, his genius might possibly have overleaped the boundary, that separates the point to which we are led by his speculations from that afterwards attained by Dr. Dalton.

As it was, the want of precision which then prevailed in chemical analysis would have rendered it impossible to collect a number of instances sufficient to establish the law as holding good universally; whilst from the cursory manner in which Mr. Higgins in the work alluded to makes

mention of the relation between the proportions in which bodies combine, and from his never returning to the subject until the principle had become generally adopted amongst chemists, we are led to infer, that he was not at the time sufficiently alive to its importance, to have attempted to follow it through those cases to which it might even then have been extended.

In the year 1808 Dr. Dalton published the first volume of his *New System of Chemical Philosophy*, in which a brief outline was given of those notions respecting the constitution of matter, which, it appears from Dr. Thomson's statement, he had explained to him and others both privately and through the medium of public lectures, for some years antecedent to that date*.

In this work he appeals to the numerous cases then ascertained in which a definite relation was found to exist between the combining quantities of different substances, as serving to establish the general law that when two bodies combine, the union takes place betwixt their component

* He had even communicated so early as 1803, to the Manchester Society, an Essay containing an outline of his speculations.

particles, in the proportion of 1 of the first to 1 of the second, 1 of the first to 2 of the second, 1 to 3, and so on.

If this be allowed, it will follow, that from the relative weight of the elements constituting any given compound that of their ultimate atoms may be inferred*; and hence when either of the same ingredients occurs in a known proportion in other bodies, the number of its atoms present in them may admit of being determined.

He therefore states, that it is one great object of his Work “to shew the importance and advantage of ascertaining the relative weights of the ultimate particles, both of simple and compound bodies; the number of simple elementary particles which constitute one compound particle; and the number of less compound particles which enter into the formation of one more compound particle.”

* That is, we are sure at least that the combining proportions represent the weight either of one atom or of more. To determine in each case which of these suppositions is most admissible, it must be considered, whether the quantity be equivalent to one or more atoms of some body whose atomic weight is already assumed to be known, and whether there be reason or not to suppose the combination to be a binary one—a point which will be discussed afterwards.

To illustrate these views, he has placed at the end of his volume a plate, in which thirty-seven bodies, including most of the supposed chemical elements, are represented by appropriate symbols; and in the explanation annexed the weights of their atoms are given according to the above mode of calculating them.

In the second volume of his work, published in 1810, he confirmed these views by facts derived from a consideration of the compounds of oxygen with hydrogen, azote, carbon, sulphur, and phosphorus, which were shewn to combine in such definite proportions, as might be reconciled to his principle; and the investigations of Berzelius, Thomson, and others, have since extended the same to all classes of chemical compounds whatsoever.

It will however be at once perceived that Dr. Dalton's doctrines comprehend two propositions, which, though mutually related, and by him closely associated, are in reality distinct; the former, a question of fact, namely, whether it be true that the proportions in which bodies combine follow any numerical law; the second, a matter of theory, whether, granting the preceding proposition, the circumstance may be accounted for

by supposing that the union takes place between the atoms that constitute the substances in question, and that in each the atoms are themselves characterised by a difference in point of weight.

To establish the first point, I will give the following examples taken from bodies whose composition has been determined with sufficient exactness :

Oxygen with Hydrogen.

Hydrogen 1, Oxygen 8* ; form Water.

———— 1, ——— 16 ; ——— Oxygenised Water.

Oxygen with Carbon.

Carbon 6, Oxygen 8 ; form Carbonic Oxide.

———— 6, ——— 16 ; ——— Carbonic Acid.

Oxygen with Sulphur.

Sulphur 16, Oxygen 8 ; form Hyposulphurous Acid.

———— 16, ——— 16 ; ——— Sulphurous Acid.

———— 16, ——— 24 ; ——— Sulphuric Acid.

Oxygen with Nitrogen.

Nitrogen 14, Oxygen 8 ; form Nitrous Oxide.

———— 14, ——— 16 ; ——— Nitrous Gas.

———— 14, ——— 24 ; ——— Hyponitrous Acid.

———— 14, ——— 32 ; ——— Nitrous Acid.

———— 14, ——— 40 ; ——— Nitric Acid.

Hydrogen with Sulphur.

Hydrogen 1, Sulphur 16 : form Sulphuretted Hydrogen.

———— 1, ——— 32 ; ——— Bisulphuretted Hydrogen.

* In all these cases the number expresses the relative weight of the combining proportions.

Hydrogen with Carbon.

Hydrogen 2, Carbon 6; form Light Carburetted Hydrogen.

———— 2, ———— 12; ———— Olefiant Gas.

The same relation extends also to compounds of the above simple bodies. Thus:

Potass with Carbonic Acid.

Potass 48, Carbonic Acid 22; form Carbonate of Potass.

———— 48, ————— 44; ———— Bicarbonate of Potass.

Potass with Oxalic Acid.

Potass 48, Oxalic Acid 36; form Oxalate of Potass.

———— 48, ————— 72; ———— Binoxalate of Potass.

———— 48, ————— 144; ———— Quadroxalate of Potass.

Alumina with Sulphuric Acid.

Sulphuric Acid 40, Alumina 18; form Sulphate of Alumina*.

———— 40, ———— 36; ———— Disulphate.

———— 40, ———— 72; ———— Trisulphate.

It is even found to hold good in the combinations between salts. Thus:

Carbonate of Magnesia with Carbonate of Lime.

Carb. of Magn. 5.25, Carb. of Lime 6.25; form Magnesian Carb. of Lime.

Carb. of Magn. 5.25, Carb. of Lime 12.50; form Bitter Spar.

And in the combinations of one sulphuret (or sulpho-salt) with another. Thus Berzelius mentioned combinations of sulphuret of arsenic with sulphuret of potassium, in which the proportions appear to be as follows:

* At least according to Dr. Thomson, "First principles of Chemistry," vol. I. p. 313.

the proportions in which bodies combine. 69

	Sulphur. Potass.	Sulphur. Arsenic.
1st Combination	56	156 or 1 to 1
2nd —————	112	156 or 2 to 1
3rd —————	168	156 or 3 to 1

The legitimate inferences from these facts are ; that the proportion of oxygen which unites with the substances mentioned is 8, that of hydrogen 1, that of carbon 6, that of sulphur 16, &c. or some multiple of the above numbers ; and consequently that the same law extends to these more elementary bodies, which Richter had laid down with regard to their primary compounds ; namely, that the same quantity of *A* which combines with a given weight of *B*, will be required to combine with that proportion of *C* which unites with the supposed quantity of *B*.

Hence the combining proportions of the above substances are termed chemical equivalents, and the following numbers will represent those of a few of the elementary substances most familiar to us.

Chemical equivalent.	
Hydrogen	1
Carbon	6
Oxygen	8
Phosphorus	12
Azote	14
Sulphur	16
Sodium	24
Potassium	40

If it be further inquired, on what principle we select these numbers for the equivalents of the bodies to which they are appended, rather than any multiple of them,—why the equivalent of carbon for instance is fixed as 6 instead of 3, or that of oxygen 8 instead of 16, we may reply, that our choice is determined by theoretical considerations, which will better admit of explanation, when we have spoken of the Theory founded upon the facts under present consideration.

But whether these numbers, or any multiples of them, be adopted, it will be equally true, that the numbers representing the chemical equivalents of all the bodies above enumerated are, if correctly calculated, multiples by a whole number of that of hydrogen, which is at once the lightest body known, and that of which the combining quantity is the smallest; a circumstance first pointed out by Dr. Prout in his interesting *Memoir** “on the relation between the specific gravity of bodies in their gaseous state, and the weight of their atoms,” where it was also shewn that they were all, according to the best analyses then made, multiples of twice the atomic weight of hydrogen, and most of them of four times that quantity.

* *Ann. of Phil.* vol. vi. 1815.

This idea, in favour of which we are prepossessed from the simplicity which its adoption would introduce into the series of numbers representing the combining proportions of bodies, was further countenanced by the elaborate researches of Dr. Thomson in his *First Principles of Chemistry*, and although other chemists of still greater authority, such as Berzelius*, have questioned the correctness of this generalization, yet if it can be shewn conclusively, that the rule holds good with respect to any two or three of the substances mentioned in the table, and especially in the case of those which we have most right to regard as elementary, a presumption will exist in favour of the extension of the same law to the rest.

Now Dumas†, by an elaborate series of experiments, conducted with the most scrupulous care, has confirmed the original statement of Prout, that whilst the atomic weight of carbon is exactly 6, that of oxygen is exactly 8 times that of hydrogen, and Marignac appears to have established that the equivalent of azote corresponds almost precisely

* Thus, according to this chemist, the atomic weight of chlorine is 35.43, and not 36.0, as Thomson states it to be; and that of bromine 78.26; the latter however is fixed almost exactly at 80.

† *Mémoires de Chimie*, 1843.

with the number 14; thus evincing that there is something real in the relation between the combining proportions of these four widely spread and fundamental elements.

Whilst therefore we admit, with Sir John Herschel*, that with regard to the other substances included in the Table whose atomic weights are higher, the question still remains undecided, and would therefore avoid accepting as true, numbers set down in accommodation to this preconceived relation, in preference to the actual results of experiment, still there seems reason to expect, that when the lower parts of the scale have once been established on a sure foundation, successful advances will be made towards the determination of the higher numbers, which may then be compared with bodies at intermediate points, and therefore no longer be referred to a standard which renders so extreme a degree of exactness requisite.

* Sir John Herschel, in his *Introduction to the Study of Natural Philosophy*, p. 307, remarks, "that it is doubtful whether such accuracy in chemical analysis has yet been attained, as to enable us to answer positively for a fraction not exceeding the 300th or 400th part of the whole quantity to be determined; and this degree of exactness at least would have been required to verify the law satisfactorily in the higher parts of the scale."

In thus imagining all other substances to be multiples of hydrogen, we set out with assuming that this, which is the lightest body known, is therefore the lightest in nature, for it is evident, that whatever inherent probability there may be in the idea of other substances being multiples of this body, depends entirely upon the latter supposition.

Now this we are scarcely warranted in laying down as certain, and indeed, I believe that when Dr. Prout, in the paper alluded to, first pointed out the numerical relation that appeared to exist between the atomic weights of various simple bodies as determined by the best authorities then existing, he alleged it chiefly as a presumption in favour of the idea of their being possibly compounded of oxygen and hydrogen, of which they appear to be multiples.

Indeed, if we could ascertain, that there were any two or three undecomposed substances, to whose atomic weight those of all other bodies in nature bore this relation, we might with some degree of plausibility conjecture that these were the elements out of which the rest were formed; but there is no necessity for assuming that one of them would prove to be hydrogen, or even any other of the bodies which have yet come under our cognizance.

The combining weights of the different bodies, whether simple or compound, being ascertained, it is easy to see how conveniently the sliding rule of Gunter may be applied, in the manner originally proposed by Dr. Wollaston*, as a mechanical substitute for the tedious arithmetical calculations, that would be requisite for determining the exact proportion of one substance equivalent to a given quantity of another.

It is not my business to describe the principle on which this sliding rule is constructed; but as the divisions in it are logometric, it is evident, that if we arrange in a tabular form a series of names indicating a number of different substances, and place them one below the other at intervals corresponding to the differences between the weights of their combining proportions, a moveable scale of numbers annexed to such a table will afford us the means of ascertaining by mere inspection, the exact proportion of all the other bodies enumerated that will be required to combine with, or neutralise, a given quantity of any one of them.

Thus in the table the bodies are so disposed, that if the number 10, which Dr. Wollaston fixed upon for the chemical equivalent of oxygen, be shifted exactly opposite to the name of that sub-

* Phil. Trans. for 1814. part i.

stance, we shall find all the others mentioned in the table likewise opposite to the number representing their combining proportion; thus sulphur will stand opposite to 40, iron to $34\frac{1}{2}$, zinc to 41; now if we wish to learn how much of the three latter substances will combine with $14\frac{1}{2}$ of oxygen, we perceive, by shifting the number 14.5 on the sliding rule opposite to the word oxygen, that 29 of sulphur, 50 of iron, and 59 of zinc, are the respective quantities; these, in the altered position of the scale, being the numbers in a line with the names of the three bodies alluded to.

This instrument, which is capable of solving a number of problems of importance both to the scientific and manufacturing chemist, and thus of affording a great saving of the time that would be otherwise spent in arithmetical calculations, is now sold by the makers of philosophical apparatus in a variety of different forms, all however constructed on the same principle, and is too generally known to require to be illustrated by a plate.

It will be immediately perceived, that the number here fixed upon for the atomic weight of oxygen is one perfectly arbitrary, and that the same purpose would be answered, if we chose to

substitute any other body as our standard, and any other number as expressive of its combining proportion, provided only that the other substances introduced into the table maintain the same relation one to the other as in the scale of Dr. Wollaston.

Accordingly, the atomic weights of bodies have been represented on several different systems.

Thomson, Wollaston, and Berzelius, for example, refer all substances to oxygen, on the ground that there is no other principle which possesses so wide a range of affinities, or enters as a component part into so many important combinations. By Thomson its atomic weight is made 1, by Wollaston 10, by Berzelius 100, a difference of little moment, as it merely involves the necessity of expressing in the one case by whole numbers, what in the other is done by fractional parts.

Thus the following are the chemical equivalents of the five bodies below enumerated, according to these three schemes.

	Thomson.	Wollaston.	Berzelius.
Hydrogen	0.125	1.25	12.5
Carbon	0.75	7.5	75.0
Oxygen	1.00	10.0	100.1
Azote	1.75	17.5	175.0
Iron	3.5	35.0	350.0

Dr. Dalton, on the other hand, preferred taking for his standard hydrogen, in which the majority of British chemists of the present day appear to follow him, and I am inclined to think that there is an advantage in so doing, as the mind apprehends somewhat more readily the relation between the atomic weights of bodies, when they are thus compared with that which is the lightest substance known, than when referred to oxygen, by means of a descending, together with an ascending scale of numbers, as in the instance before us.

This latter scale would also possess an additional recommendation, if it should eventually turn out that the combining proportions of other bodies are multiples of that of hydrogen, as we should then be able to dispense entirely with fractions, and express by whole numbers the relation which the equivalents of all bodies bear one to the other. The oxygen scale, on the other hand, *necessarily* involves the employment of decimals, which in an affair of memory seem objectionable, and which, if they cannot be entirely done away with, should at least be introduced as sparingly as possible.

Leaving, however, the comparative merits of

the two scales of chemical equivalents to be settled by each person according to the facility he finds in applying them to his purposes, let us consider the exceptions that have been adduced to the laws with regard to the construction of bodies, and see how far they are calculated to throw doubts upon the soundness of the principle, which is taken for granted equally, whichever of these scales we employ.

In the first place, it sometimes happens, that the only known combination existing between two bodies, is not in the proportion which would be indicated by the number representing their respective chemical equivalents.

Thus 1 of hydrogen combines with 8 of oxygen, and the latter with 14 of nitrogen. We should therefore infer, that the quantity of hydrogen which would combine with 14 of nitrogen ought to be 1, whereas it is 3; the only well ascertained compound of the latter ingredients being ammonia, which consists of 14 by weight of nitrogen, and 3 of hydrogen.

In other cases, where several combinations of two bodies occur, the ratio between the numbers is not as 1—2—3, or a multiple of the smallest, but as 1—1½—2, or some other intermediate quantity.

It may be observed, however, that in these cases the very exception seems to prove the rule; for with regard to the first case, although 3 is not the equivalent of hydrogen, yet it is a multiple of that quantity; and with regard to the second, the relation of one half, or one quarter, of the smaller number is always preserved in the other combining quantities, so that it is plain, that a certain regularity is still maintained in the midst of these apparent anomalies, and that the combinations take place even here agreeably to some fixed and settled principle.

Many of these exceptions indeed have disappeared, in proportion to the progress of discovery: thus a few years ago we were acquainted with only two compounds of sulphur and oxygen, the sulphurous and sulphuric acids, the former composed of 16 sulphur and 16 oxygen, the latter of 16 sulphur and 24 oxygen, the proportion of oxygen in the two compounds being therefore as 2 and as 3 to 1 of sulphur.

But the discovery of the hyposulphurous acid has since removed this anomaly, by presenting us with a compound of 16 sulphur and 8 oxygen, so that the proportion of the latter is to that in which it exists in the second as 1 to 2.

It is probable, therefore, that in many cases the

exception is only apparent, whilst in others it seems not unlikely that two equivalents of one ingredient may combine respectively with two, three, and four equivalents of the other, as in the oxides of lead, which, according to Dr. Thompson, consist of

$$\text{Lead } 104 \times 2 = 208 \quad \text{Oxygen } 8 \times 2 = 16$$

$$\text{—— } 104 \times 2 = 208 \quad \text{—— } 8 \times 3 = 24$$

$$\text{—— } 104 \times 2 = 208 \quad \text{—— } 8 \times 4 = 32$$

to which we must add the Din oxide (since discovered) Lead $104 \times 2 = 208$ Oxygen $8 \times 1 = 8$.

Instances of the same kind are very common among compounds of an organic nature, and their frequent occurrence has led some distinguished chemists to doubt the truth of the atomic theory altogether.

“The numbers,” says Dr. Prout, “conventionally employed by chemists, and termed atomic weights, or chemical equivalents, I am disposed to view in a very different light from that in which they are usually viewed at present.

“Supposing them to be correct, they no doubt represent in general the quantities in which bodies most usually combine, but by no means always. Indeed, they appear to me to be often nothing more than one term of a natural series

peculiar to each body, and determining its composition. Thus 9, the number assumed to represent the combining weight of water, is to be considered only as one term of the series 3 : 6 : 9 : 12 : 15, &c. in all which proportions (and perhaps in still lower submultiples of them) this fluid enters into combination, perhaps quite as often as in the proportion 9, especially in the organic kingdom.

“ Chemists have already a glimpse of this important fact, when they speak of bodies uniting to others in the proportions of two, three, or more atoms, which, in fact, are nothing more or less than different terms of a natural series, such as that above alluded to.”

No doubt the view here taken by Dr. Prout of the composition of bodies affords an exact expression of the phenomena divested of all hypothesis ; but I am not aware of any facts which do not equally admit of being referred to the theory more commonly adopted, neither do I see any absurdity in supposing, that in organic compounds, where the terms of the series, according to Dr. Prout, are in the case of water represented as 3. 6. 9. 12. 15., the true relation may be as 9 : 18 : 27 : 36 : 45 corresponding to 1 : 2 : 3 : 4 : 5, atoms of water.

Both these modes of representing the relation

between the quantities of the ingredients which constitute an existing combination come to the same point, and if we only keep in view the possibility of combinations occurring, especially in the organic kingdom, in the more complex relation of 4 or five proportionals of the one, to one or more proportionals of the other, we shall perhaps be as little liable to have our experimental researches warped by the theory to which we endeavour to accommodate them, as we should be by confining ourselves to that more general expression of the facts which Dr. Prout has recommended.

Not long after Dr. Dalton in England had directed the attention of chemists to the relation existing between the weights of bodies which combine in different proportions, Gay-Lussac in France in conjunction with Humboldt established a similar correspondence between the volumes of oxygen and hydrogen which unite together, proving that they combined in the proportion of one volume of the first to two of the second. Shortly after the publication of Dr. Dalton's first volume, the French philosopher extended the same inference generally to the combinations between gases; shewing that they united in the exact

relation of 1 volume of the one, to 1, 2, 3, or some other whole number of volumes of the second. Thus one volume of carbonic acid and one volume of ammonia form carbonate of ammonia; one of nitrogen and three of hydrogen form ammonia; one of chlorine and one of hydrogen form muriatic acid. The same law applies to vapours, such as those of alcohol and ether, as well as to true gases.

M. Gay-Lussac even rendered it probable that the combinations between solids and gases follow the same principle; that quantity of the former uniting with one or more volumes of the latter, which, if existing in the form of vapour, would have occupied an equal bulk.

Thus as carbon 6, and oxygen 16, by weight form carbonic acid, 100 cubic inches of oxygen will combine with 12.7 grains of carbon.

For 100 cubic inches of oxygen weigh 33.8888, and,

as $16 : 6 :: 33.8888 : 12.7$.

Now it is inferred * that 12.7 grains of carbon

* Because in the combustion of pure carbon in oxygen no change of volume ensues. Now the quantity consumed is in the ratio of 12.7 grains of carbon to 100 cubic inches of oxygen, so that 12.7 grains in the state of vapour occupy the space of 100 cubic inches.

occupy when in vapour 100 cubic inches, or exactly the same space as 33.8888 grains of oxygen, so that the combining quantities of the two bodies correspond in point of volume, no less than in the number of atoms of which a volume of each is made up.

When aeriform fluids combine together, and produce by their union a new gas, they generally contract in bulk, or occupy less space than they did when separate. Now Gay-Lussac found that when this takes place, they contract either to one half, one quarter, one third, two thirds, or some other quantity bearing an exact proportion to their antecedent bulk. Thus, carbonic oxide 2 volumes, with oxygen 1 volume, form together 1 volume of carbonic acid gas, there being a contraction of $\frac{1}{3}$ rd; 3 volumes of hydrogen, and 1 of nitrogen form 2 volumes of ammonia, the gases contracting to one half, and so with the rest.

We perceive then, that whether we regard the weight or the volume of the bodies which enter into combination with each other, a very simple relation seems to exist between them, the quantity of the one being either equal to that of the other, twice as great, three times as great, or some other multiple of its quantity; whilst the weights of the

respective quantities would appear, so far as experiment has gone, to follow the same law.

Hence a correspondence must exist between the volumes of different bodies, that unite, and their specific gravities; and Dr. Prout has shewn with much sagacity, that the combining proportions of the several gases bear in the majority of cases the same ratio to that of hydrogen, which their specific gravity does to that of the latter body; whilst in other instances their specific gravity is half as great. In the cases of oxygen and fluosilicic acid gases alone, the specific gravity would, according to this method of reckoning, exceed that of hydrogen twice as much as its combining proportion does, which may be seen in the following table, wherein are stated the weights of the chemical equivalents of a few gaseous bodies, and their specific gravities as compared with hydrogen, which is represented in both instances as unity.

	Chemical equivalent by weight.	Specific gravity as compared to hydrogen.
<i>First Series.</i>		
Oxygen	8	16
Fluosilicic acid.....	26	52
<i>Second Series.</i>		
Hydrogen	1	1
Carbon vapour	6	6

	Chemical equivalent by weight.	Specific gravity as com- pared to hydrogen.
Phosphorus vapour	12	12
Azotic gas	14	14
Sulphur vapour	16	16
Tellurium vapour	32	32
Chlorine gas	36	36
Arsenic vapour	38	38
Selenium vapour.	40	40
Iodine vapour *	124	124

Third Series.

Ammoniacal gas	17	8.5
Hydrocyanic acid vapour	27	13.5
Deutoxide of azote	30	15.0
Muriatic acid	37	18.5
Hydriodic acid	125	62.5

In the year 1808 the celebrated Swedish chemist Berzelius, in consequence of a perusal of Richter's work, was induced to undertake an investigation of the numerical proportions in which different bodies combine, when they neutralize each other. The views of Dalton becoming at that time known, his ideas expanded as he proceeded, and he was thereby encouraged to undertake a series of analyses, unrivalled per-

* The relation between the atomic weight and specific gravity of compound gases and vapours, may be seen in Dr. Thomson's *First Principles*, vol. ii. Appendix, Table II.

haps even up to this time for their number and their accuracy, which have appeared in successive volumes of the Memoirs of the Academy of Sciences of Stockholm, and in other publications. The results of these labours led him to lay down certain laws relative to chemical combinations, which, though in general only to be considered as corollaries from those determined by Dalton, claim nevertheless a short separate consideration. These views are indeed necessary for the due understanding of his nomenclature, and of the symbolical language he has introduced into chemistry, both which have been long adopted on the continent, and have gradually found their way amongst the men of science in this country also.

Berzelius was the first to establish what is now generally admitted, namely, that the law of combination by definite proportions pervades the whole of nature, so that not only minerals, though consisting merely of earthly ingredients, are subject to its influence, but vegetable and animal products also are formed agreeably to it.

Simple bodies combine in the ratio of one proportional of the one, to one, two, three, or four proportionals of the other.

The compounds of bodies considered simple are

distinguished into binary, or of two ingredients ; ternary, or of three ; quaternary, or of four. Now binary compounds often unite agreeably to the same system as simple bodies, but sometimes in a more complicated manner, as in the ratio of 2 to 3, 3 to 4, &c.

In all the combinations formed by an union of two or more binary compounds possessing a common principle, the quantity of the latter in one of the component parts is a multiple of that in which it occurs in the other by the numbers 2, 3, or 4.

Thus 100 grains of sulphuric acid will neutralize 120 of potass. Now

100 grains of sulphuric acid contain of oxygen	60.
120 ditto of potass	20.

Hence the weight of oxygen in the electro-positive element, or potass, is to that in the electro-negative one, sulphuric acid, as 1 to 3.

Double salts are also influenced by the same law. In the tartrate of potash and soda, for example, the oxygen of the potash is exactly equal to the oxygen of the soda ; and the oxygen in the tartaric acid which neutralizes the potash is equal to that of the soda.

The acids of phosphorus, nitrogen, and arsenic are exceptions to this principle ; for here the

quantity of oxygen in the oxides which combine with them is as one or more fifths in the case of the phosphoric, nitric, and arsenic, and as one or two thirds in that of the phosphorous, nitrous, and arsenious acids.

When two ternary compounds, having different bases but the same acid, combine, the quantity of oxygen in the one is always a multiple by a whole number of its quantity in the other. Thus alum is composed of

Tersulphate of Alumina, Acid 3 prop.	Oxygen = 72.
Sulphate of Potass, ——— 1 prop.	———— = 24.

When two ternary compounds, having the same base, but different acids, combine, the proportion of oxygen in the base combined with one of the acids, is a multiple by a whole number of the proportion present in that combined with the other.

Thus in the mineral called Datholite, the lime is divided between two acids, the boracic and silicic, in such proportions, that the oxygen in that portion of the base which is combined with the one, is exactly equal to that in the portion united to the other; whilst in the blue copper ore, which consists of carbonate and hydrate of copper, the quantity of oxygen present in the copper combined with the acid, is double

that existing in the portion united with the water.

But these canons, which Berzelius has put forward as supported by a vast assemblage of facts, and to which he seems to appeal, as to a test by which to try the accuracy of his experimental results, appear, when attentively considered, to be, so far as they are true, necessary consequences of the law of Definite Proportions laid down by Dalton.

Dr. Thomson has justly remarked, that where the neutral salts are concerned, the principle itself is only another mode of expressing the fact, that all the bases are protoxides of the metals which form them, and therefore contain but one proportional of oxygen. Now under such circumstances, it is evident that the quantity of oxygen present in the acid must either be the same as that in the oxide with which it combines, that is, one proportional, or a multiple of that quantity by a whole number.

But it is not *universally* true that all the bases are in the state of a protoxide; in a few they contain other proportions of oxygen. In the persalts of iron for instance, where the oxygen of the base is to the metal as $1\frac{1}{2}$ to 1, this relation

cannot always prevail. In the sulphate, indeed, where the oxygen of the acid is to its radical sulphur as 3 to 1, the rule holds good, but not so in the phosphate, where it is to the phosphorus as 5 to 1; in the sesquinitrate, where $1\frac{1}{2}$ proportional of acid contains $7\frac{1}{2}$ of oxygen to $1\frac{1}{2}$ of nitrogen; and in other instances that might be easily adduced. In these, it is evident, no numerical proportion subsists between the oxygen of the base and that of the acid which combines with it.

In subsalts too, which are composed of 1 proportional of acid and 2 of base, the law of Berzelius fails, wherever the acid contains an uneven number of proportionals of oxygen. Thus we have

	In the base.	In the acid.
A nitrate of alumina containing of oxygen..	6	5
Ditto	9	5
An arseniate of iron	6	5
A nitrate of lead	2	5
An acetate of lead	2	3
An acetate of copper	2	3
A nitrate of bismuth	2	5

To none of these instances does the law of Berzelius seem to apply; so that although the verification by experiment of its general truth

affords a valuable confirmation of the doctrine of definite proportions, yet it would seem, that it cannot be depended on *à priori*, beyond the limits embraced by the theory of which it is one of the consequences.

CHAPTER III.

Scientific names given to compound bodies often of necessity prolix, and wanting in precision—Hence the introduction of symbols into chemistry—Three kinds proposed for adoption — Comparison of their respective objects and advantages—Formulæ founded upon the algebraical method of notation generally preferred.

NO sooner had inquiries into the chemical properties of matter, and into the changes produced by mixture, brought to light a numerous catalogue of new substances which do not present themselves in nature, made known the elements out of which they were compounded, and set forth the relations which they bore to each other, than those arbitrary terms, by which bodies had been denoted in earlier times, became superseded amongst men of science by others more expressive of their real or their supposed constitution. This

improvement we owe to the French school of chemistry, and whatever exceptions may be taken to a nomenclature, necessarily based on theoretical principles, and therefore liable to be superseded, or to be rendered inappropriate, as new views came into vogue, or old errors became exploded, still it must be admitted, that in certain departments of the Science, as for instance in that relating to the acids and the salts, no memory could without its assistance have mastered the whole list of names which expressed the various compounds put before it, and no understanding have retained a distinct idea of the nature and constitution of each.

One unavoidable evil however of a nomenclature constructed on the above principles was, that it rendered the names introduced prolix, in direct proportion to the complexity of the bodies themselves—for however brief might be the terms indicating the supposed elements of matter, the compounds formed by the union of two or more of them could not have other than long-winded designations.

The word sulphur, for instance, does not occupy much time in pronouncing, or even in being committed to writing, but the acids formed by it in conjunction with oxygen, viz. the hyposulphurous,

sulphurous, and sulphuric acids, cannot be expressed so concisely, and when a salt compounded of any one of the above acids with a base is to be denoted, such for instance as the hyposulphate, the sulphite, or the sulphate, of oxide of iron, the most compendious way of expressing it, and that even one to which some writers might object as wanting in precision, requires the employment of at least three separate words.

Thus putting the simplest case with which we have to deal, neither an acid nor a salt can be indicated except by a complicated, and consequently a tedious mode of expression, and when moreover, as frequently happens, we are obliged to distinguish between two salts, by stating the proportion as well as the nature of their elements, the prolixity of the designation is still further increased.

But this is not all, for, as Dr. Whewell observed long ago, "the existing nomenclature, however ingeniously constructed it may be, seems incapable of adapting itself to the expression of the various combinations which will probably be discovered, and is even now with difficulty rendered applicable to compounds of more than two ingredients.

"In this latter, the simplest case supposable, although there may be no difficulty in expressing

the composition clearly by means of the language of chemistry, yet the nomenclature is often imperfect.

“ Thus the words *hyposulphate*, *sulphite*, *sulphate*, are defective, in not shewing the relative quantity of oxygen in the acid; and moreover, such terms are liable to become improper by the discovery of new compounds. The same may be said of such expressions as *peroxide*, *persulphate*.

“ Nor is this nomenclature capable of extending itself, by virtue of its own rules, in proportion as discovery extends. If new combinations of manganese and oxygen should hereafter be discovered, they must receive arbitrary, and probably anomalous designations. The oxide, deuteroxide, peroxide, manganesious, and manganesic acid, do not at all obviously refer to compounds, in which the proportions of oxygen are 1, $1\frac{1}{2}$, 2, 3, 4; and if we should find a combination in which the proportion of acid is $2\frac{1}{2}$ or $3\frac{1}{2}$, there is no denomination ready for it, nor would it be easy to find a good one. This applies equally to very many cases.

“ In other cases phrases are used, as the *sulphato-tricarbonate of lead* for instance, which, though capable of a right interpretation, do not

sufficiently interpret themselves; and even such can only be constructed for a few detached instances.

“When the constitution is at all less simple than in the above examples, the expression to describe it becomes still more difficult to construct. If we have 3 proportionals of lime and 4 of silica, there is no very compendious chemical name for the compound.

“On the other hand, where the compound consists of more than two ingredients, the received nomenclature is obviously incapable of expressing its composition, except by a roundabout phraseology.

“Thus stilbite is said to be 1 proportional of trisilicate of lime, combined with 4 proportionals of trisilicate of alumina, and 6 proportionals of water; whereas all we are warranted by direct experiment in asserting is, that 15 proportionals of silica, 4 of alumina, 1 of lime, and 6 of water are present. The manner therefore in which these are arranged is hypothetical, and as such, ought not to make a part of the definition of the substance.”

For these reasons the invention of some abbreviated mode of writing, by which the composition

of a substance could be more speedily and at the same time more accurately expressed, was soon felt to be a *desideratum*, and this led to the adoption of Symbols, by which the meaning, which in ordinary writing was designated, and that imperfectly, by a tedious combination of words, might be conveyed by one or two characters, easily apprehended, and speedily noted down.

Two objects then aimed at in symbolic writing were, greater conciseness, and greater precision, and to this must be added a third, which the celebrated Dalton particularly cherished, having reference rather to the better comprehension of his own theoretical views as to the cause of the definite proportions which bodies affect, than to a clearer and readier indication of the proportions themselves.

Thus we may distinguish three modes of chemical notation, constructed for as many distinct uses; the first, that of Dalton, intended to represent the supposed collocation of the particles one to the other; the second, designed merely to convey a clearer conception of the relations as to weight existing between the several component parts of a compound; the third, a more abbreviated method of expressing the same thing,

in which economy of time and labour was amongst the objects aimed at; these methods corresponding in some sort to the three modes that have been in use at various periods of the world's history, for conveying information on ordinary matters by writing.

Dr. Dalton then, in order to effect his purpose of expressing, not merely the number of particles of each ingredient which he conceived to constitute a given compound, but likewise the very mode in which he supposed them to be united, proposed a sort of pictorial representation of every compound which he specified, just as in the infancy of writing, substances were indicated, not by an arbitrary character, but by a sign bearing some remote resemblance to the object itself.

This therefore may be denominated the hieroglyphical mode of chemical notation; it was of considerable use in the infancy of the atomic theory, by familiarizing the minds of men of science to the mode in which combinations take place, and by thus paving a more ready way to the reception of this important doctrine. Even now it may have its advantages, as conveying to the mind of a learner a clearer notion of the proportion between the elements of a compound body and of their relation to each other; and in those

which consist only of two or three ingredients, a symbolic representation of them after Dr. Dalton's plan might be nearly as concise as any other. But it would be difficult, consistently with brevity, to express in this manner any of those more complicated combinations that meet us in every stage of modern chemical inquiry, as for instance, in the compounds of cyanogen, or in the proximate principles of organic life.

Nevertheless, there has been a theory introduced by certain French chemists, especially by Dumas and Laurent, which renders the use of symbols constructed upon the plan of Dalton's still sometimes convenient. I allude to the Theory of Types which will be considered in a subsequent chapter, the characteristic of this being to attach importance, to the *collocation* of the several component atoms, as well as to their relative proportions, thus reviving another of those general principles, which the penetration of the Philosopher of Manchester led him at an earlier period to anticipate.

The second mode of symbolic writing is that in which the system of notation adopted in Algebra is applied to meet the purposes of Chemistry. This method, whilst it is recommended by its greater perspicuity, and by being intelligible to

all educated persons, has the advantage also of involving no hypothesis, and of being equally available in the hands of individuals, who have taken up the most opposite views of the collocation of the several atoms, or who dismiss the question as altogether foreign to their consideration. It may therefore be in some sense compared to the alphabetical mode of writing in use amongst civilized nations; the characters indeed may differ, the words formed by a combination of those characters may be very various, but the principles on which they are put together to express certain sounds and ideas are in all countries the same.

The third method of notation, which has been recommended by the authority of several great continental chemists, and especially of Berzelius, in so far as it differs from the one last alluded to, may be compared to a system of short-hand rather than to one of ordinary writing, its express object being to abbreviate, so far as is consistent with perspicuity, the mode of notation above described. Accordingly the two latter modes are those chiefly in use amongst chemists, the Daltonian being only occasionally employed for the purposes of illustration.

Of the algebraical method of notation therefore

in the improved form in which it is now presented to us by Poggendorff and Liebig*, as well as of the more abbreviated system which was proposed by Berzelius, it will be proper to give some short account, as it seems impossible, in the present state of chemical knowledge, to peruse any single Essay or Treatise connected with this science without some previous acquaintance with the principles upon which they proceed.

With respect to the symbols indicating those substances which have hitherto been undecomposed, there is no difference between the two methods, the marks originally proposed by Berzelius being still adhered to by most chemists.

Simple bodies, not metallic, are denoted merely by the initial letter of the Latin name of each; thus S. denotes sulphur, C. carbon, P. phosphorus, O. oxygen, H. hydrogen.

A metal, whose initial letter is not common to any other elementary body, is denoted, like the preceding substances, by that letter alone, as U=uranium, K=kalium (potassium) L=lithium. But if the initial be common to another metal, or to either of the simple non-metallic substances, then the two first letters are taken, as Si=silicium, Au=

* Handwörterbuch.

aurum ; whilst, if both the first and second letters be common to more than one metal, the first *different consonant* is then annexed to the initial letter, instead of the second letter of the name. Thus Sb. denotes antimony, (stibium) Sn=tin, (stannum). In each case 1 atom of the body named is implied.

The following table then will present the symbols of most of the simple bodies at present known*.

Elements.	Symb.	Elements.	Symb.	Elements.	Symb.
Aluminium	Al	Gold (Aurum)	Au	Potassium (Kalium) .	K
Antimony (Stibium) .	Sb	Hydrogen	H	Rhodium	R
Arsenic	As	Iodine	I	Selenium	Se
Barium	Ba	Iridium	Ir	Silicon	Si
Bismuth	Bi	Iron (ferrum)	Fe	Silver (Argentum) . .	Ag
Boron	B	Lead (Plumbum) . . .	Pb	Sodium (Natrium) . .	Na
Bromine	Br	Lithium	L	Strontium	Sr
Cadmium	Cd	Magnesium	Mg	Sulphur	S
Calcium	Ca	Manganese	Mn	Tellurium	Te
Carbon	C	Mercury (Hydrargyrum)	Hg	Thorium	Th
Cerium	Ce	Molybdenum	Mo	Tin (Stannum)	Sn
Chlorine	Cl	Nickel	Ni	Titanium	Ti
Chromium	Cr	Nitrogen	N	Tungsten (Wolfram)	W
Cobalt	Co	Osmium	Os	Vanadium	V
Columbium (Tantalum)	Ta	Oxygen	O	Uranium	U
Copper (Cuprum) . . .	Cu	Palladium	Pd	Yttrium	Y
Fluorine	F	Phosphorus	P	Zinc	Zn
Glucinium	G	Platinum	Pt	Zirconium	Zr

* Certain compound bodies of frequent occurrence are also denoted by single Symbols: thus water is expressed by Aq.; Ammonia by Am.; and Cyanogen by Cy.

When the combinations of any of these simple bodies with oxygen are to be expressed, Berzelius used the symbol of the substance, with as many dots over it as there were proportionals of oxygen; thus oxide of copper with one proportional of oxygen was indicated by Cu^{\cdot} , the same with two proportionals by $\text{Cu}^{\cdot\cdot}$; sulphurous acid was S^{\cdot} , sulphuric acid $\text{S}^{\cdot\cdot}$; but when two proportionals of any base were combined with the oxygen, Berzelius printed its initial letter with an horizontal line drawn through it; for which device, however, others have substituted a similar mark underneath the letter. Thus if we adopted Berzelius's view of the composition of water, we should denote the presence of two atoms of hydrogen in it by H^{\cdot} ; and should express the same number of atoms of the metal aluminium combined with three of oxygen in alumina by $\text{Al}^{\cdot\cdot}$.

In like manner the compounds of sulphur were denoted by the mark ' placed over the symbol of the other element: thus $\text{As}^{'}$ denoted sulphuret of arsenic, $\text{As}^{''}$ the bisulphuret, &c.

At present however, in lieu of these dots and commas, it is more generally preferred to use the algebraical mode of expression, merely omitting the usual sign of addition. Thus for potass,

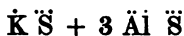
instead of $K + O$, we write $K O$; for protoxide of iron $Fe O$, and where more than 1 atom of either ingredient is to be expressed, the number is denoted by a figure placed at the right of the symbol. Thus $Fe^2 O^3$ designates the compound of 2 atoms of iron with 3 of oxygen, or what is commonly called the peroxide. If it be wished to express that 2 atoms of this compound are present, we place the formula within brackets, adding to the left, outside of the bracket, the number of atoms we intend to designate. Thus $2 (Fe^2 O^3)$ denotes 2 atoms of peroxide of iron.

In Berzelius's method, in order to express salts, the symbols of the acid and base were brought into juxtaposition, with as many dots over each symbol as corresponded with the number of proportionals of oxygen belonging to each; and when either of the component parts had more than 1 proportional, a figure annexed indicated the number.

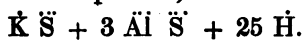
Thus $Cu \ddot{S}$ was sulphate of copper with 1 proportional of acid; $Cu \ddot{S}^2$ sulphate of copper with 2 proportionals.

To express compound salts, the symbols for each were brought together by means of an hyphen +; and if the quantity of either exceeded a single proportional, the number was indicated by a figure placed immediately after the hyphen.

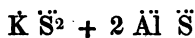
Thus alum being, according to Dr. Thomson, compounded of 1 proportional of sulphate of potass, and 3 proportionals of sulphate of alumina, was written thus :



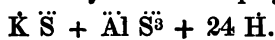
or more completely, to express the number of proportionals of water present,



whilst as, according to Phillips, it consists of 2 proportionals of sulphate of alumina, united to 1 of bisulphate of potass, it ought to be represented as follows :



By Berzelius himself it was considered a compound of 1 atom of sulphate of potass, with 1 atom of trisulphate of alumina, and 24 atoms of water ; hence the symbol he employed was



But here also, as in the former instance, the algebraical method is at present most commonly adhered to, with the omission of the usual signs, and a few other unimportant changes. Thus K O, S O³ is the formula for sulphate of potass, the comma denoting, that the sulphuric acid (S O³) is united to the potass (K O.) When 2 salts are combined, the symbol of addition is em-

ployed, thus $\text{K O}, \text{S O}^3 + \text{H O}, \text{S O}^3$ is bisulphate of potass, a compound of sulphate of potass with hydrated sulphuric acid.

According to this method alum would be expressed by

$\text{K O}, \text{S O}^3 + \text{Al}^2 \text{O}^3, 3 \text{S O}^3 + 24 \text{H O}$
instead of

$\text{K} \ddot{\text{S}} + \text{Al} \ddot{\text{S}}^3 + 24 \text{H}$
as by Berzelius.

Such is a brief sketch of the principles upon which Berzelius proceeded in establishing his system of chemical notation, as well as of the modifications recently introduced into it by Liebig and Poggendorff.

I have thought it best to make some mention of both these schemes, because although most chemists will find it convenient to employ some abbreviated forms of expression, it seems doubtful whether any particular amount of them can be recommended for universal adoption, since the necessity for any abbreviation at all will vary, with the habits of the individual, the nature of his inquiries, and the objects for which his notes were designed.

A chemist for example, the character of whose mind enables him quickly to perceive, and clearly

to recollect, minute distinctions, may find a much more concise style of notation convenient than would be advisable for others; one who is engaged in the analysis of organic compounds will be more sensible of the utility of such symbols, than another who is conversant chiefly with a less complicated class of combinations; and one who notes down the results of his experiments for the benefit of private reference, and not with any immediate view to others, may indulge in a more concise and intricate system of notation, than would be convenient, where the latter object is contemplated.

As the shortest road is proverbially not always the most expeditious, so in chemical notation more time may often be lost in correcting our own blunders and those of the compositor, where dots and commas of many sorts are introduced in the place of initial letters to express certain elements, than was gained by the more compendious method of expression employed.

In conclusion then it may be remarked, that for the purpose of rendering more intelligible to beginners the mode in which various bodies are supposed to combine, the Daltonian method of notation may still be of use, just as pictorial

representation often comes in aid of verbal description to convey the idea of a complex object.

But where the design is to state in the clearest and least hypothetical terms the nature of a series of combinations, a mode of notation as closely as possible approaching to that adopted in Algebra seems preferable—remembering always, that as in Algebra certain signs are omitted for the sake of greater brevity, the same license may be allowable when we apply its principles to Chemistry, such abbreviations being of course most advisable in cases, where, by reason of the greater number of elements involved, the expression of them at whole length would occupy so much space, as to prevent the whole from being comprehended at a glance.

It may perhaps render the above remarks more intelligible to those who are not already conversant with the subject to which it relates, if I proceed to illustrate a little farther these three methods of notation, by exhibiting some examples of each in juxtaposition on the two next pages of this work.

Examples of the Three Modes of Notation.

DALTONIAN.	ALGEBRAIC.	BERZELIAN.
S Y M B O L S O F		
Hydrogen \odot Oxygen \circ Azote $\textcircled{1}$	Hydrogen H Oxygen O	Oxygen . Sulphur , The rest as in
Sulphur \oplus Carbon \bullet Iron $\textcircled{1}$ Lead $\textcircled{\text{L}}$	Azote N Sulphur S Carbon C Iron Fe Lead Pl.	the second column. In each case 2 atoms are denoted by — underneath.
Protoxide of Iron $\textcircled{1}\circ$	..... Fe O .....	..... \text{Fe
Peroxide of Iron $\begin{matrix} \circ \\ \textcircled{1} \\ \circ\circ \\ \textcircled{1} \end{matrix}$	..... Fe 2 O 3 .....	..... \text{Fe
Protoxide of Lead $\textcircled{\text{L}}\circ$	..... Pl O .....	..... \text{Pl
Deutoxide of Lead $\circ\textcircled{\text{L}}\circ$	..... Pl O 2 .....	..... \text{Pl
Peroxide of Lead $\begin{matrix} \textcircled{\text{L}} \\ \circ \\ \circ\textcircled{\text{L}}\circ \end{matrix}$	..... Pl 2 O 3 .....	..... \text{Pl
Sulphuret of Lead $\textcircled{\text{L}}\oplus$	..... Pl S .....	..... \text{Pl
Water ..... $\circ\odot$	..... H O .....	..... \text{H
Oxygenized Water ..... $\circ\odot\circ$	..... H O 2 .....	..... \text{H

Carbonic Oxide .....	● ○	.....C O .....	.....C
Carbonic Acid .....	○ ● ○	.....C O 2 .....	.....C
Oxalic Acid .....	○ ● ○ ○	.....C 2 O 3 .....	.....C
Ammonia* .....	⊙ ⊕ ⊕ ⊕	.....N 2 H 3 .....	.....N 2 H 3
Nitrous Oxide .....	⊕ ⊕ ⊕	.....N 2 O .....	.....N
Nitrous Gas .....	.....⊕ ⊕	.....N O .....	.....N
Nitric Acid .....	.....○ ⊕ ○	.....N O 2 .....	.....N
Hyponitrous Acid .....	.....○ ⊕ ○ ○	.....N O 3 .....	.....N
Nitrous Acid .....	.....○ ⊕ ○ ⊕ ○	.....N 2 O 3 .....	.....N
Alcohol.....	⊙ ● ○ ○ ⊙ ●	.....C 2 H 3 O.....	.....C 2 H 3
Ether .....	● ⊙ ⊙ ○ ○ ⊙ ○ ● ○	.....C 4 H 5 O.....	.....C 4 H 5

* In order to compress the whole within the page, Dalton's mode of arranging his symbols has in some cases been departed from, but his equivalents have been adopted throughout, so that the one for nitrogen is only half what is generally employed.

APPENDIX TO CHAPTER III.

It will be perceived, that I have assumed a slight acquaintance with the nomenclature at least of chemistry on the part of those to whom the remarks in the preceding chapter are addressed.

It may, however, be well to state, that whilst the original framers of this Nomenclature were contented with affixing the termination *ic* to the name of an acidifiable base, in order to express an acid containing the largest proportion of oxygen with which it was thought capable of combining, and that of *ous* to one with a smaller portion of the same so-called *acidifying principle*, it has since been found necessary sometimes to attach to both the words thus compounded the prefix *hypo*, in order to express lower or intermediate grades of oxydation since discovered.

Thus whilst sulphuric acid denotes, as it did in Lavoisier's time, sulphur in its utmost degree of saturation with oxygen, and sulphurous acid the same with a smaller amount, the term *hyposulphurous* will imply an acid with less oxygen than the sulphurous, and *hyposulphuric* one with less than the sulphuric, but with more than the sulphurous contains.

And so with respect to salts, the French chemists proposed the termination *ate* for a compound, the acid ingredient of which contained the maximum of oxygen, and *ite* for one with the minimum. Subsequently, however, the subject has been found to present a much greater complication, and in consequence it has here also been found requisite to prefix certain terms, as expressive of the number of proportionals of acid or of base present in each compound.

Thus the original denominations of sulphate, nitrate, phosphate, and of sulphite, nitrite, phosphite, are at present regarded as only sufficient to define a salt, when made up of equal proportionals of acid and of base.

Accordingly, the term carbonate of potass ought to be confined to the compound of 1 prop. of carbonic acid, and 1 of potass, but when 2 proportionals of acid are present, the prefix *bi* is employed; when 3 prop., that of *ter*; when 4, *quadr*; when $1\frac{1}{2}$, *sesqui*.

In like manner, when the number of proportionals of base is 2, the prefix *di* or *dis* is adopted; when 3, *tris*; when four, *tetrakis*; the Greek numerals being used in this case, the Latin ones in the former.

For example, *binoxalate* of potass is a compound of 2 of acid and of 1 of base; *quadxalate* of 4 of the former to 1 of the latter. *Sesquinirate* of iron is formed of $1\frac{1}{2}$ acid to 1 of the metallic oxide; *tersilicate* of iron of 3 of the former to 1 of the latter.

Dinitrate of bismuth denotes 1 of acid to 2 of the oxide; *trisnirate* of alumina, 1 of acid to 3 of the earth; *trisilicate* of iron, 3 of base to 1 of silicic acid.

CHAPTER IV.

ON THE EXISTENCE OF ATOMS.

Arguments in favour of the existence of atoms, drawn—from the definite proportions in which bodies combine—from the occurrence of several distinct compounds all possessing the same constitution—from the definite form belonging naturally to each substance—from the existence of a boundary to the atmosphere, and of a certain limit to the evaporation of all bodies whatsoever—from the size of material objects being circumscribed within certain boundaries, both in the direction of the great and the small—from all which circumstances it must be concluded, that there exists somewhere a point beyond which division cannot be carried, and consequently that all matter consists of an assemblage of atoms.

HAVING in the two preceding chapters communicated a brief statement of what has been ascertained with respect to the laws of combination, and of the methods adopted for expressing symbolically the relations between the component parts of bodies, I shall next proceed to the more speculative branch of the subject, by shew-

ing, that the facts which have been above detailed admit of being explained on a few very simple postulates by the corpuscular theory, whereas, if we adopt the one opposed to it, they appear, if not irreconcilable to its principles, at least in no degree accounted for by them.

If matter be infinitely divisible, no reason can be assigned why bodies should unite in certain proportions, and not in others; we should rather expect, that, as their smallest conceivable portions differ in quantity only, and not in quality, from the largest, they should all possess the same affinities, and that consequently the number of combinations taking place between different substances should be as infinite, as are the parts into which they themselves admit of being separated.

Such indeed was the opinion of Berthollet, who contended, that bodies have in reality an equal tendency to combine in any proportion whatsoever, and that the effects we usually attribute to chemical or elective attraction depend upon the operation of cohesion, elasticity, and other forces; yet even he did not pretend to deny, that in *point of fact* the generality of simple bodies affect certain combinations in preference to others; nor would it have been easy for him to have accounted for this preference to certain definite quantities,

if nature were supposed to have set no limit to the divisibility of matter.

But if, adopting the principles of the atomic theory, we assume, that combination takes place only between the *ultimate* particles of which matter is composed, and that each distinct elementary substance is composed of atoms, differing from the rest in point of density or weight, the law, which I have stated with respect to the combinations of bodies, will be seen to flow necessarily from such data.

For let us suppose two substances, which we will call A and B, to combine with each other in three different proportions, and that these proportions be represented, so that the quantity of A remaining the same, the quantity of B varies. Under these circumstances, it is evident, that the compounds will probably consist of 1 atom of A with respectively 1, 2, and 3 atoms of B, and that the combining quantities of B must be the same as the weight, either of one, or of several of its atoms; in other words, it must either correspond with its atomic weight, or be some multiple of it.

Let us then assume, that the weight of an atom of A is 8, and that of an atom of B 14; then the combining quantities, in the three com-

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pounds stated as above, ought to be no other than those which follow ; viz.

A 8 + B 14 A 8 + B 28 A 8 + B 42,
the numbers attached to B representing, respectively, 1, 2, and 3 atoms of that ingredient.

Accordingly, it is taken for granted by chemists, that some one of the terms of the series representing the proportions in which a body enters into combination with others, indicates the weight of its atoms as compared with that of other substances.

Thus, neglecting small fractional differences, the following table will denote the atomic weight of a few substances hitherto undecomposed, referred to hydrogen as a standard of comparison :

Hydrogen	1
Carbon	6
Oxygen	8
Phosphorus	12
Azote	14
Sulphur	16
Calcium	20
Sodium	24
Iron	28
Copper	32
Chlorine	36
Potassium	40

In selecting these numbers rather than any multiples or fractions of them for the relative weights

of single atoms, we are guided by theoretical considerations, and therefore cannot pretend to absolute certainty.

It seems reasonable to suppose, that the most stable combination between two elements would be a *binary* one, or in the proportion of atom to atom, since the attracting force of the atom of a given body can hardly be supposed to exist in the same intensity for a second atom of another element, after it has been in part expended in uniting with the first *.

* Nevertheless, this opinion, plausible as to my mind it appears, was, at one time at least, controverted by one of the greatest of modern chemists.

Berzelius assumed, that those bodies which possessed the strongest affinity for oxygen, united with it as in the proportion of 2 atoms to 1, and all his old tables of the atomic constitution of bodies are in fact constructed upon this principle.

The reasons he assigns for this inference are curious, reminding one of those of the Indian philosopher, for considering that the smallest portion of matter visible to the eye must consist of at least six atoms. (see p. 8.)

He contends, "that a combination of atom with atom does not exist in nature, because being composed of two spheres, it would only be extended in a linear direction; whereas whatever possesses substance is composed of 3, 4, 5, 6, or some still larger number of spherical atoms; the sphere constituting, as it were, the germ of those geometrical forms, which the crystals of all bodies exhibit with so much regularity." Vol. iii. p. 102.

118 *Existence of Atoms proved from the definite*

Moreover, it happens in most cases of chemical union, that the force of affinity has to overcome the mutual repulsion, which had previously kept the particles at a greater distance asunder, thus rendering the body itself less dense.

Now it is evident, that when each particle of A is united to only a single particle of B, the repulsive force, which it has to overcome, will be only half that which it must encounter, when a union takes place between it and two particles of B; and consequently, that the combination in the former instance must be in that proportion stronger.

Accordingly as the only stable combination between hydrogen and oxygen is water, in which, as has been seen, the proportions are as 1 to 8, the numbers in question are regarded as the atomic weights of these two simple bodies.

The atomic weight of carbon is considered to be 6, because this is the smallest quantity which is capable of combining with oxygen, and consequently the compound in which these proportions exist is regarded as being made up of single atoms of each ingredient, whilst carbonic acid, in which twice the quantity of oxygen is present, we view as a compound consisting of 2 atoms of the latter to 1 of the former.

This conclusion is confirmed by observing that the second atom of oxygen is less closely combined than the first, since hydrogen converts carbonic acid into carbonic oxide, but cannot reduce the latter by abstracting the remaining atom of oxygen, and it is also inferred from finding, that 6 by weight of carbon when in vapour would occupy precisely the same dimensions as 16 of oxygen. Now as to form water oxygen unites with hydrogen in the proportion of 1 volume to 2, analogy would lead us to infer, that the number of atoms of oxygen in carbonic acid in proportion to those of the carbon must be twice as great, whilst in carbonic oxide, where the volume of the carbon is half that of the oxygen, the number of atoms of each would be the same.

Chemists have proceeded on similar grounds in fixing upon the numbers given for the atomic weights of the other simple bodies enumerated, and have laid down for our guidance a set of rules founded upon the above principle, which may be seen detailed in Gmelin's Chemistry, p. 44, in Turner's, and other standard Treatises.

It is evident however, that those who saw ground to differ from them in the principles of their selection, might fix upon other numbers, without debarring themselves from the use of the

120 *Also from the facts of Isomerism, and from the*
works in which these are adopted, provided they
took care to refer them all to one uniform stan-
dard.

The most direct argument then in favour of
the existence of atoms is deduced from the defi-
nite proportions in which matter combines, but
Baron Liebig has advanced another subsidiary to
it, derived from those later discoveries in chemis-
try, which will form the subject of a subsequent
chapter.

He justly observes, that the existence of several
distinct bodies possessing the same composition
both as regards the nature and the proportion of
their elements, is only reconcilable with the doc-
trine of atoms. According to this view of the
constitution of matter, it is conceivable that dif-
ferent bodies may be built up out of the same
atoms by arranging them differently, but that
if they were produced by a sort of interpenetra-
tion of their constituent elements, in the manner
which the opponents of the atomic theory are
compelled to suppose, the properties resulting
from the union must be in all cases the same.

Indeed the whole doctrine of chemical substi-
tutions, and the theory of types founded upon it,
rests upon this hypothesis, and it would be diffi-

cult to convey a clear conception of the ordinary changes which take place in chemistry, without assuming the existence of particles of a certain definite weight, and undeviating size.

The conclusions to which we have been thus brought are fortified by arguments drawn from other branches of science. Thus if matter were infinitely divisible, it would seem that a substance could not be made up of particles at all times the same in point of size and figure. Now a difference in the ultimate component parts seems scarcely reconcilable with the definite form belonging to each aggregate, when its constituents are allowed to arrange themselves in their natural order, uninfluenced by disturbing causes.

It has been ascertained by Haüy and others, that every solid body possesses a peculiar geometrical arrangement, from which all the manifold varieties of form it presents can be shewn to be derivable.

All of these figures may be reduced to six primary types, enumerated in works of mineralogy, and the kind of crystallization assumed by the same mineral body, is the result of the apposition of an assemblage of smaller crystals, possessing the fundamental type of the species, in a variety

of different modes, all, however, conformable to certain fixed laws.

Thus these secondary forms, infinite as they may appear, are all capable of being classed under certain groups; the members of the same group passing into each other, but not those belonging to different groups.

Now whatever may be the primary cause of these distinctions in crystalline arrangement, their permanency in the same species seems to shew, that each must be made up of parts as unchangeable in size and figure, as in the other chemical and physical properties that belong to them.

Even in the mode in which these secondary crystals are grouped together, a certain regularity seems to be preserved, which bears some analogy to the law of multiples in chemistry. It appears that the numerical exponents or indices by which the positions of the faces of crystals of the same species are regulated, stand always in some relation, and generally in a proportion not greater than two, three, or four. Thus it will be seen from Mr. Haidinger's work, (vol. i. p. 73.) that the axes of two scalene four-sided pyramids, of which the one is derived from the other, are towards each other in the ratio of $\frac{1}{2} : 1$, if the derived pyramid is more obtuse; in the ratio of $2 : 1$, if the derived

pyramid is more acute than the given one. This regularity, though of course attributable to a very different cause from that of the definite proportions in which the elements of compound bodies unite, is so far connected with the latter, inasmuch as it implies a certain permanency of size and figure in the component particles, which renders the crystals formed out of them subject to laws equally fixed and immutable.

A discovery indeed has been recently made, which may at first sight appear to throw some doubts upon the soundness of this conclusion.

It has been found, that many bodies are capable of assuming two distinct crystalline forms no wise related, according to the circumstances under which they had been brought into the solid condition. Bodies which thus present themselves under two different forms are termed *dimorphous*, and the number of those already known is so great, that it may perhaps be questioned, whether there be any body in nature, which constantly occurs in the same physical condition under all circumstances.

A familiar instance of dimorphism is exhibited in the case of carbonate of lime, which, without

any change in its chemical properties or its composition, is found, sometimes in the form of calcareous spar, sometimes in that of arragonite, the one belonging to the rhomboidal, the other to the regular prismatic system.

I shall return to this curious subject in a subsequent part of this volume, but on the present occasion need only remark, that the argument in favour of a permanency of size and figure belonging to the component particles of a body is not weakened by any such fact, so long as it can be shewn, that the crystalline forms which a body assumes, be they few or be they many, are subject to certain definite mathematical laws.

If this be once admitted, it will follow necessarily, that its component particles must be all the same in point of size and figure, and unless the crystallization of substances in general could be suspected to vary indefinitely, and to run through an infinite variety of phases, there is nothing in the new discoveries as to Dimorphism which need shake our belief in the doctrine we have set forth.

I dare not speak with equal assurance of another argument on the same side which was brought forward in my former edition, inasmuch

as its soundness has been contested by so high an authority as Dr. Whewell.

Nevertheless, as the idea appears to have emanated from no less a man than Dr. Wollaston, it would be fitting here to introduce some mention of it, were it only as an illustration, of that marvellous acuteness of mental vision, that quickness in descrying distinctions, and seizing upon analogies indiscernible to mankind in general, which peculiarly characterized that eminent philosopher in all departments of physical research.

Dr. Wollaston then labors to shew, that on the hypothesis of matter being infinitely divisible, there ought, strictly speaking, to be no positive limit to the extent of our atmosphere, but that each of the planets would be surrounded by an aërial fluid, gradually decreasing indeed in density in proportion to the distance from its surface, but still indefinite in point of extent.

For the force of repulsion, which tends to keep the particles of an aëriform fluid at a certain distance apart, must operate wherever any portion of air exists, and although in the higher regions of the atmosphere the repulsive force would be diminished by the rarity of the medium, yet, in consequence of that very rarity, it would be in

a less degree counteracted by the superincumbent pressure.

On the other hand, if we suppose the atmosphere to be made up of atoms, or to consist of a finite number of elementary molecules, the parts of which are linked together by a bond which nothing can disunite, it will follow, that at a certain height above the surface, the force of gravity, which tends to draw the particles towards the earth, would counterbalance the power of elasticity or mutual repulsion, which gives them a contrary tendency, and wherever that point exists, there a boundary to the extent of the atmosphere must be found.

Dr. Wollaston, though unable to discover by his method, what might be the case with respect to our own atmosphere, has rendered it probable, that that which surrounds other of the celestial bodies belonging to the same system, is limited in extent.

He shews, for instance, that if all space were filled with matter, as on the supposition of the atmosphere being unlimited would be the case, the heavenly bodies must attract to themselves an aërial fluid of more or less density, in proportion to their respective bulks.

He therefore proceeds to inquire, whether the atmosphere surrounding the sun is of that density which it ought to be from the attraction of a mass of matter of its enormous magnitude. As the density of air may be estimated by its power of refracting the rays of light, the degree in which the apparent position of a planet, when seen through a solar atmosphere, differs from its real one, may serve to measure the density of the medium, which intercepts its rays.

The occultation of Venus by the body of the sun furnished him with the means of determining this question, and it was concluded from the observations made upon this planet, that its apparent position was not in the least affected by any refraction of the rays proceeding from it through a solar atmosphere, thus justifying the conclusion, that none existed of that density which would have surrounded it, had matter been uniformly diffused throughout space.

To obviate the objection arising from the heat of the sun, which might diminish the density of its atmosphere in a degree beyond calculation, a corresponding series of observations was made with respect to Jupiter, and with similar results; the atmosphere surrounding that planet not ap-

pearing of the density, which would have belonged to it under the same circumstances.

Professor Leslie*, availing himself of a suggestion thrown out by the celebrated Kepler, has been conducted to the same final result by a very different train of reasoning, as he argues from the phenomena of twilight, that the atmosphere surrounding our own planet is likewise of limited extent†, thus inferring directly, what Dr. Wollaston concluded to be the case from analogical reasoning.

Dr. Faraday, in an ingenious Memoir read before the Royal Society‡, has corroborated these views respecting the limited extent of the atmosphere, by shewing that there is nothing anomalous in such an arrangement, other bodies being

* See article Meteorology in the supplement to the Encyclopædia Britannica. It may be doubted however, whether professor Leslie's conclusions exactly meet the question, since they do not appear to disprove the possibility of an atmosphere pervading space, provided it be so attenuated, as not to reflect in an appreciable degree the rays of light, and consequently not to interfere with the phenomena of twilight.

† According to Kepler, the atmosphere extended to about 49 miles above the earth's surface; but professor Leslie, from other considerations, calculates it, as ascending to the height of 1638 miles.

‡ On the limits to evaporation, Phil. Trans. for 1826.

subject to a law of an analogous kind. He proves, for instance, that, contrary to what was commonly thought, there is a certain temperature, and for most bodies not a very low one, at which all evaporation of their substance is stopped, the force of gravity belonging to the particles which compose them, here counterpoising the force of repulsion, which tends to separate them beyond the limits of cohesion.

Between 60° and 70° of Fahrenheit quicksilver rises in vapour, until the vessel containing it is filled with an *atmosphere* of that fluid, a fact which is substantiated by suspending over it a sheet of gold leaf, which soon becomes whitened and impregnated by the volatile metal.

Hence it would appear, that under ordinary temperatures the force of repulsion was more than a match for that of gravitation. But if we reduce the heat to that of Zero, although the mercury retains its fluidity, still no evaporation takes place from its surface, the elasticity of its particles being no longer sufficiently powerful to overcome the resistance opposed by their weight.

Now, I think, it may be inferred, agreeably to the principles on which Dr. Wollaston has proceeded, that if the matter composing this metal had been capable of infinite division, evaporation

would have gone on in it at all temperatures up to the point of the absolute privation of heat. For in this case, the repulsive force caused by caloric ought to be exerted between the smallest portions of matter as well as the larger ones, so that, however feeble the power of repulsion may be, yet, as we suppose it exerted on parts of matter so minute, as to possess in a still slighter degree the counteracting force of gravity, it would continue to produce a certain effect.

Objections have been taken to this reasoning by the eminent French chemist, Mons. Dumas *, but on grounds which do not appear to me materially to affect its validity. It is contended, that the cold of the upper regions may be so intense as to reduce the gases composing our atmosphere to a state of solidity, or at least to render them liquid, in either of which cases a limit would be set to their further expansion, even though their particles admitted of indefinite division. But the author of this objection does not appear to have noticed, that his own distinguished countryman Mons. Fourier, in his celebrated Memoir on the Heat of the Globe, has assigned to the celestial

* Leçons sur la Philosophie Chimique, page 235.

spaces a temperature far too high, to allow of the consolidation, or liquefaction, of oxygen and nitrogen gases, bodies which resist the utmost intensity of cold that has ever yet been attained by artificial means, being proof even against that produced by the evaporation of frozen carbonic acid, although creating in the bodies contiguous a temperature probably nearly 100 deg. lower than that which is calculated as existing in those portions of space that lie at the extreme limits of our atmosphere*.

The hypothesis of Mons. Dumas seems in fact a revival of the Ptolemaic doctrine of crystalline spheres, encircling our globe, and constituting a sort of substantial firmament around it; but its admission would be attended with difficulties from which the ancient theory was exempt, since the sun and other celestial luminaries, which in the latter were included within this boundary, would, according to the former view, lie beyond it.

The obstruction which this palpable barrier would create to the transmission of light and heat, I leave for opticians to speculate upon.

* Fourier calculates, that the temperature diffused through space, by the aggregate effect of so many suns radiating heat, is not much inferior to that existing at the poles of our own planet.

I presume, however, that all the above proofs would alike be set aside by Dr. Whewell, since he objects to Wollaston's argument upon the ground, that the finite surface of the atmosphere no more proves the atomic constitution of air, than the finite surface of water in a vessel proves the atomic constitution of water*.

I shall, therefore, leave for the present this question in the hands of geometricians, who will be supposed better qualified to discuss it than chemists, hoping however to indemnify myself for the want of that support which I had formerly conceived to have been rendered by it to the theory just advocated, by appealing to considerations of another kind suggested to us by the writings of the author last alluded to in favour of the existence of atoms—considerations founded upon the analogy of created things in general, which Dr. Whewell has insisted upon in his *Bridgewater Treatise*.

"Vast," says he, "as are the parts and proportions of the universe, we still appear to be able to perceive that it is finite; the subordination of magnitudes, and numbers, and classes appears to have its limits. Thus, for any thing we can dis-

* See Report of the Proceedings of the British Association in 1839, at Birmingham, p. 26.

cover, the sun is the largest body in the universe; at any rate, bodies of the order of the sun are the largest of which we have any evidence.

“We know of no substance denser than platina, and it is improbable that one denser, or at least much denser, should ever be detected. The largest animals which exist in the sea or on the land, are almost certainly known to us. We may venture also to say, that the smallest animals which possess in their structure a clear analogy with larger ones have been already seen. Many of the animals which the microscope detects are as complete and complex in their organization as those of larger size; but beyond a certain point, they appear, as they become more minute, to be reduced to an homogeneity and simplicity of composition which almost excludes them from the domain of animal life.

“The smallest microscopical objects which can be supposed to be organic, are points, or gelatinous globules, or threads, in which no distinct organs, interior or exterior, can be discovered. These, it is clear, cannot be considered as indicating an indefinite progression of animal life in a descending scale of minuteness. We can, mathematically speaking, conceive one of these animals as perfect and complicated in its structure as an

elephant or an eagle, but we do not find it so in nature.

“It appears, on the contrary, in these objects, as if we were, at a certain point of magnitude, reaching the boundaries of the animal world.

“We need not here consider the hypothesis and opinions to which these ambiguous objects have given rise; but without any theory they tend to shew, that the subordination of organic life is finite on the side of the little as well as of the great.”

Now whilst this argument from analogy may be adduced in favour of the existence of ultimate atoms, I cannot but conceive, that the ready explanation which the latter hypothesis affords of this limit to the progression of organic life in the descending scale, is in itself a still stronger corroboration of it.

If, as Dr. Whewell observes, solids and fluids consist of particles of a definite, though exceeding smallness, which cannot further be divided or diminished, it is manifest, that we have in the smallness of these particles a limit to the possible size of the vessels and organs of animals. The fluids, which are secreted, and which circulate in the body of a mite, must needs consist of a vast number of particles, or they would not be fluids;

and an animal might be so much smaller than a mite, that its tubes could not contain a sufficient collection of the atoms of matter to carry on its functions.

From all these concurrent arguments, we seem to be justified in concluding, that a limit is to be assigned to the actual divisibility of matter ; and consequently, that we must suppose the existence of certain ultimate particles, stamped, as Newton conjectured, in the beginning of time, by the hands of the Almighty, with permanent characters, and still retaining the exact size and figure, no less than other subtle qualities and relations which were imparted to them at the first moment of their creation.

The particles of the several substances existing in nature may thus deserve to be regarded as the alphabet, composing the great volume which records the wisdom and goodness of the Creator ; since the characters which go to make it up, far from appearing to be thrown together by chance, and collected into unmeaning groups, as the Epicureans contended to have been the case, denote in every page, by the import they convey, the agency of mind, and speak a language, which, so far as it is intelligible to our finite faculties, is every way worthy of its divine Author.

To those who object to this view as visionary and chimerical, and who would suspend their belief, until they can obtain more direct and palpable evidence of its truth than we have been enabled to offer, it may be suggested, that an exact correspondence with the phenomena which it is intended to explain, is in fact all the proof that can be reasonably expected, with regard to the existence of bodies infinitely too minute to be brought within the cognizance of our senses.

There is indeed some analogy in this respect, between the theory I have here embraced for the purpose of accounting for the constitution of matter, and that which in another work it has been my ambition to advocate as explanatory of the phenomena of volcanos, although I would by no means wish to represent the latter as ranking so high in the scale of probability as the former.

The two theories however have this in common, namely, that the cause assumed to account for the facts can in neither instance be directly proved to exist, the one from the extreme minuteness, the other from the unapproachable depth, necessarily assigned to the bodies to which we ascribe the phenomena; so that the truth of both rests equally upon what may be termed *circum-*

* Description of active and extinct Volcanos, 2nd edition, London, 1848. See especially chap. XXXIX.

stantial evidence, namely, on its enabling us to account for the facts which observation discloses, better than any other assumption would do.

"Philosophy," says Hartley, "is the art of deciphering the mysteries of nature; and every theory, which can explain the phenomena, has the same evidence in its favour, that it is possible the key of a cipher can have from its explaining that cipher."

Now the doctrine of atoms affords a key which exactly corresponds to a very complicated series of effects; and hence, though it wants that complete evidence that would be afforded if we could shew the existence of the cause, has nevertheless certain claims upon our assent, at least until another principle be proposed more adequate to account for the phenomena.

It is therefore not without reason, that a profound philosopher of the present day* has pronounced the atomic theory, or the law of definite proportions, which is the same thing presented in a form divested of all hypothesis, as, after the laws of mechanics, the most important which the study of nature has yet disclosed. "The extreme simplicity," he observes, "which characterizes it, and which is itself an indication, not unequivocal, of its elevated rank in the scale of physical truths,

* Herschel's Preliminary Discourse, p. 305.

had the effect of causing it to be announced at once by Mr. Dalton in its most general terms, on the contemplation of a few instances, without passing through subordinate stages of painful inductive assent by the intermedium of subordinate laws, such as, had the contrary course been pursued by him, would have been naturally preparatory to it, and such as would have led others to it by the prosecution of Wenzel and Richter's researches, had they been duly attended to.

"This is in fact an example, and a most remarkable one, of the effect of that natural propensity to generalize and simplify, which, if it occasionally leads to overhasty conclusions, limited or disproved by further experience, is yet the legitimate parent of all our most valuable and our soundest results. Instances like this, where great and indeed immeasurable steps in our knowledge of nature are made at once, and almost without intellectual effort, are well calculated to raise our hopes of the future progress of science, and by pointing out the simplest and most obvious combinations, as those which are actually found to be most agreeable to the harmony of creation, to hold out the cheering prospect of difficulties diminishing as we advance, instead of thickening around us in increasing complexity."

CHAPTER V.

Whether combination takes place between single atoms or between groups of them—proof that heat does not resolve a body into its ultimate particles—nor yet chemical attraction, if it be admitted that the specific heat of a body is connected with its atomic weight—Dulong's and Regnault's researches on this subject—Those of Avogadro and Neumann—Summary of the conclusions to which we are led by the above facts.

IN the former chapter it was my design to shew, that the law of definite proportions established by Dalton renders the opinion, that matter is susceptible of infinite division, no longer tenable, and hence inclines us to adopt that hypothesis with respect to atoms, which we find the philosophers of Greece and Rome to have advocated, in some of their writings that have come down to us.

But admitting the truth of the dogma itself, and adopting their ideas on the subject in question

down to the point which we have hitherto reached, it may still admit of a question, whether combinations between bodies may not be more readily explained, by imagining them to take place between certain definite groups of atoms, than by assuming, with the immortal philosopher whom we regard as the Father of the Atomic Theory, as received in modern times, that they resulted from the union of single atoms of each ingredient.

It has been contended by Dumas, that when a body is resolved by heat into the condition of a gas, so that its several parts exist in a state of mutual repulsion, the parts so repelling each other cannot be viewed as single atoms, but must consist of clusters of them.

Such also is the conclusion to which Dr. Prout had arrived in 1834, when he published his *Bridge-water Treatise*, and in his paper "On the relation of the specific gravities of gaseous bodies and the weights of their Atoms," which bears the date of 1815 and 1816, the same principle appears to have been recognised.

It is grounded upon the fact, that in many cases where two gases unite and form a third, either no condensation in them occurs at all, or one less considerable than what ought to happen

if the combination took place between the ultimate particles of which they are supposed to consist.

For it is contended, that in order that an union should take place between A and B, every atom of A must be brought into the nearest possible contiguity to one or more atoms of B, so as to form together one single self-repulsive particle of the resulting body, and that if this latter be a gas, the space occupied by it would thus at most be only half of that which had been filled by its component parts when separate. If hydrogen and oxygen, for instance, unite and constitute water, the latter in the form of steam ought to occupy only one half the space of its constituents, whereas it takes up in fact two thirds.

In like manner chlorine and hydrogen, when they unite to form muriatic gas, occupy the same space as before, instead of only half of it, whilst nitrogen 1, hydrogen 3, in producing ammonia, are condensed into half their original volume, whereas the space they ought to occupy upon this assumption would be only one fourth of what it had been previously.

In these and other instances of a similar kind, it is contended, that the union must take place, not between the ultimate particles of each body,

but between groups of them, because the resulting compound occupies more space than it ought to do upon the former supposition.

When, for instance, muriatic acid gas is produced by the union of equal volumes of chlorine and of hydrogen gases, we may suppose the parts which combine to consist of several particles united together by the force of attraction, but each of these groups to become subdivided into two smaller ones, when combination takes place between the two.

The assumption however upon which the whole of this is grounded—namely, that all elastic fluids expand in an equal degree with equal increments of heat—is one which, it has been argued in an able paper of Dr. C. Henry's, published some years ago in the *Philosophical Magazine*, ought to be regarded as somewhat gratuitous.

It may be, for instance, that the expansion produced by a certain temperature upon the particles of muriatic acid, is exactly twice as great as that which took place in the cases of the chlorine and hydrogen previously, and by this hypothesis the Daltonian doctrine would still admit of being maintained.

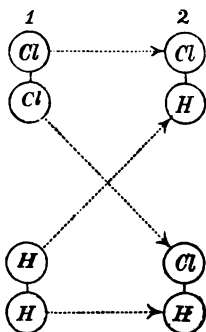
Thus two distinct explanations may doubtless be given of the phenomena, as will be seen by the

following diagrams representing the views taken by the two classes of philosophers on this subject.

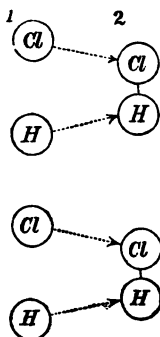
S Y M B O L

Of Hy- Of Chlo- Of Muriatic
drogen H rine ... Cl Acid Cl
 H

DUMAS' AND PROUT'S.



DALTON AND HENRY'S.



No. 1. represents the atoms before combination takes place; 2. afterwards. The direction of the arrows shews the change of place undergone by each atom when it enters into combination.

In the former, the double atoms of chlorine and of hydrogen are supposed to be separated, so as to form two atoms of muriatic acid, which therefore will occupy the same space as their component parts did previously.

In the latter, the muriatic acid is supposed to be formed of single atoms of chlorine and hydrogen, but to have its particles kept asunder to a distance twice as great as before.

We are at liberty of course to take our choice of either of these hypotheses, but the former appears to me intrinsically the more probable, and I do not see, why the philosopher who admits that matter is in its essence divisible *ad infinitum*, inasmuch as no body can be conceived so minute as to be destitute of parts, should scruple to suppose, that heat may be capable of separating a body only into parts of one degree of minuteness, and chemical affinity into others of still greater tenuity.

Nor ought this supposition to be regarded as militating against the original theory of Dalton, but rather as carrying out its fundamental principles, for as the most direct proof we possess that matter is made up of indivisible particles, consists in the definite nature of its combinations, it is evident, that if the limit to which division can be carried by chemical means is assumed to be at all times definite and unchangeable, we are only following in the footsteps of the founder of the Atomic Theory when we call these ultimate portions of matter by the name of atoms, even

though there be reason for believing that they are aggregates of many.

The same supposition is also put forward to enable us to account for the want of correspondence between the combining weights and the combining volumes of certain gases, although even here a definite proportion is in both cases equally maintained.

Oxygen, for example, uniting with hydrogen, in the proportion, by weight, of eight to one, forms water, and as this is the more stable of the two known combinations of these two elements with one another, it seems probable that an equal number of atoms of either ingredient concurs to form it, in which case the weight of an atom of oxygen, as compared to that of an atom of hydrogen, will be as eight to one. But if these be taken as the relative atomic weights of the two elements, twice the number of atoms of oxygen must be present in a given volume of oxygen gas, as in the corresponding one of hydrogen, because, to form water, exactly two volumes of hydrogen unite with one volume of oxygen.

Now these anomalies may be reconciled by assuming, 1st, That all bodies, when converted into a state of gas, are resolved into certain

groups of particles between which repulsion takes place, but that these by chemical means are often still further subdivided into smaller groups, which bear, however, always a certain numerical relation to the former.

Those who desire to prosecute this inquiry further, will do well to consult Dr. Prout's Bridge-water Treatise, in which the arguments in favour of the existence of molecular groups are clearly stated, and many curious deductions made from the principle assumed*. They may also refer to the *Leçons sur la Philosophie Chimique*, to which allusion has already been made, for a more profound disquisition on the subject, carrying out the ideas which the author M. Dumas had first suggested in the Introduction to his *Traité de*

* Laurent, in a recent Memoir on the Silicates (*Comptes Rendus de Chémie* 1849), contends, that in the case of the metals combinations take place between groups of atoms and not between single ones. He adopts this hypothesis, in order to reconcile the substitution of Fe^4 , Hg^4 , Mg^4 for H^2 , K^2 , &c., according to the binary theory of salts, which will be explained in a future chapter. By supposing the protoxide and peroxide of iron, &c. to consist of groups of atoms differing one from the other, as for instance the protoxide of a group of 12 atoms, the peroxide of one of 8, he reconciles the combining proportions in either case with the quantity of hydrogen displaced, so that protoxide and peroxide of iron

Chémie appliquée aux Arts, the first volume of which appeared in 1828.

In summing up the conclusions to which he had been brought by his elaborate review of the difficulties that beset the whole of this abstruse subject, the philosopher alluded to proposes to designate that description of molecular groups into which bodies are resolved by heat, physical atoms; and those simpler groups into which their affinities for other bodies often subdivide them, as chemical ones, and although persons disposed to be hypercritical may object to the application of the term in such senses as the above, as they may also do to such a solecism in language as the expression, *a compound atom*, which it has been found convenient to employ, yet I conceive that either use of the word may be defended, if we only recollect, that the question now amongst

will bear the same relation one to the other, as methylene and etherine do amongst organic compounds. (See Chap. VII.)

Thus sulphuric acid, or sulphate of hydrogen $\text{SO}^4 + \text{H}^2$

Sulphate of protoxide of iron $\text{SO}^4 + \text{Fe}(12^2)$

———— peroxide of iron $\text{SO}^4 + \text{Fe}(8)^2$

Oxide of methylene $\text{O} + (\text{C}^2\text{H}^4)^2$

———— etherine $\text{O} + (\text{C}^4\text{H}^8)^2$

In order to understand this notation, it must be recollected, that Laurent regards water as OH^2 , and not OH , as in this and other English works it is held to be,

men of science is no longer whether in a mathematical sense matter be capable of indefinite division, but whether our knowledge of nature does not justify us in concluding, that its great Author has fixed a limit to its actual divisibility.

In this case, if we have good reason for believing, that this division can be carried to a *certain fixed point* by heat, and to a still farther, but still a fixed and definite limit, by chemical means, the former class of particles may perhaps, without involving any absurdity, be styled *physical atoms*, and the latter *chemical ones*.

But that even the latter are in reality made up of a number of particles, or in other words, that chemical agencies may not resolve matter into its ultimate component parts, has been inferred from the curious and elaborate researches of M. Dulong and Petit on the Specific Heat of Bodies.

By the specific heat of a body we mean the relative quantity of caloric necessary to raise its temperature a certain number of degrees, a problem which, as may be seen by reference to the standard treatises on chemistry, Crawford proposed to determine, by mixing together a hotter and colder body in known quantities, and marking the resulting temperature.

If the specific heat of the two were the same, the latter ought to be the exact mean between that of the fluids employed, as is the case when equal portions of water, one at 100°, the other at 50°, are intermingled, but when the first requires more specific heat than the second, a greater amount of heat will be necessary to raise it a given number of degrees, and consequently the resulting temperature will be below the mean, after mixing it with a warmer liquid. In this way, by referring other liquids to water as a standard, and employing the latter as one of the liquids in each experiment, Crawford presented us with a table of the relative specific heats of the bodies at that time best known.

This same question has since been examined by Messrs. Dulong and Petit* upon a different principle, namely, from the time which each substance takes in cooling down a certain number of degrees, when surrounded by a thick bed of ice in the act of melting, in conformity with the law, that polished metallic surfaces lose equal amounts of heat in equal times.

Thus, in order to determine the specific heat of the metals, they were severally introduced, in a

* Annales de Chimie 1819, vol. X.

state of fine powder, into the vessel in which they underwent cooling, into the axis of which was inserted a delicate thermometer, as a means of measuring the rate of cooling.

The space between this vessel and the external one surrounded by the ice was rendered air-tight, and exhausted by means of an air-pump.

By this method they determined the specific heat of bismuth, lead, gold, platinum, tin, silver, tellurium, zinc, copper, nickel, iron, cobalt, and sulphur, whilst by the old method of mixtures, proceeding upon the principle of Crawford, they ascertained that of mercury, platinum, antimony, and glass. The specific heat of silver, zinc, copper, and iron, was deduced by both methods, and with results nearly in accordance one with the other.

More recently, Monsr. Regnault*, a living French philosopher of great eminence, has re-examined the subject, by the aid of a more refined apparatus, and with more scrupulous exactness, proceeding in all cases upon the plan of Crawford, which he regards as preferable to the one which Dulong and Petit had adopted.

His results accord in most instances very nearly with those of the former philosophers, and

* *Ann. de Chimie* 1840 et seq.

where any marked discrepancy exists, it is in cases where the method of cooling had been employed which seems subject to more sources of error than the other.

Now the joint inquiries of these eminent experimentalists have established this curious result—namely, that those bodies whose particles are the heaviest, or whose atomic weight is greatest, have the least specific heat.

Thus, whilst the specific heat of platinum, compared to that of water, is as 3 to 100, its atomic weight is as 99 to 9.

Hence we are led to suspect, that each particle of a body, whatever may be its nature or its specific gravity, requires the same amount of heat as a part of its constitution, so that the reason why a given quantity of water takes up so much more than a corresponding one of platinum, is, that so many more particles of it than of the metal are required in order to constitute an equal weight of matter.

Let us endeavour to test the truth of this hypothesis, by comparing the numbers set down as representing the atomic weights of certain solid bodies with their respective specific heats, and seeing whether any more exact correspondence

between the two than has been hinted at, can be shewn to prevail.

If then the principle we aim at establishing be correct, it will follow, that by multiplying the atomic weight of a substance into its specific heat, we ought always to obtain a constant quantity.

How nearly this is true in many instances, may be shewn by the following Table, in which the results of Dulong's and Petit's, as well as of Regnault's experiments, are alike given, and in which, assuming the latter to be the more accurate, the sum obtained by multiplying the atomic weights by the specific heats is set down in the fifth column, so that it may be at once perceived, how far the results of experiment differ from those to which we should be led by calculation, and within what limits they agree.

Name of the substance.	Specific heat according to Dulong and Petit.	Specific heat according to Regnault.	Atomic weight adopted by Regnault reduced to the hydrog. scale.	Sum of the atomic weights multiplied by the specific heats.
Water	1.0000	1.00800		
Oil of Turpentine .....	.....	0.42593		
Glass .....	.....	0.19768		
Iron	0.1100	0.11379	27.14	3.0852
Zinc	0.0927	0.09555	33.00	3.0820
Copper	0.0949	0.09515	31.65	3.0172
Lead	0.0293	0.03140	103.56	3.2581
Tin	0.0514	0.05623	58.82	3.3121
Nickel	0.1035	0.10863	29.59	3.2176
Cobalt	0.1498	0.10696	29.52	3.1628
Platinum	0.0314	0.03243	98.68	3.2054
Sulphur	0.1880	0.20259	16.09	3.2657
Mercury	0.0332	0.03332	101.27	3.3743
Bismuth	0.0288	0.03084	105.50	3.2536
Phosphorus ....	.....	0.1740	32.00	5.5680
Bromine .....	.....	0.0845	80.00	6.6560
Silver	0.0557	0.05701	108.12	6.1742
Arsenic .....	.....	0.08140	75.21	6.1326
Antimony .....	.....	0.05077	129.04	6.5615
Gold	0.0298	0.03244	99.44	6.4623
Iodine .....	.....	0.05412	126.36	6.8462
Carbon .....	.....	0.241	6.0	1.4460

Now it is to be observed, that in eleven of these cases, namely, iron, zinc, copper, lead, tin, nickel, cobalt, platinum, sulphur, mercury, and bismuth, the product obtained by multiplying the atomic weight into the specific heat deduced by Regnault from his experiments is 3, the decimals varying within a range of 0 to 3; whilst in six others, namely, in silver, arsenic, antimony, gold, bromine, and iodine, the number obtained is twice 3, or 6, the decimals varying from 4 to 8.

Carbon presents an anomaly, but this Regnault gets over, by supposing the real atomic weight of that form of it which enters into combination, to be double that usually supposed, viz. 12, in which case the product of the atomic weight multiplied into its specific heat would be 2.89.

The number given for phosphorus is 5.568, or, if the atomic weight be taken at 16, 2.784, which deviates more from the rule than that of any other substance in the list, and in his last paper Regnault has fixed the specific weight of potassium* at 0.54, which, considering its atomic weight to be 39, would give only 2.106 as the product of the one multiplied into the other.

Nevertheless, in spite of these apparent ano-

* Ann. de Chimie, July 1849, where also are given the specific heats of phosphorus and bromine.

malies, when we consider that the results have been in many instances arrived at alike by two distinct processes, the most exact of which, that of Regnault's, accords best of the two with theory, the coincidences are certainly too numerous to be regarded as accidental.

Regnault indeed has himself pointed out some of the sources, from which error is liable to arise in experiments of this nature: one of them is, that the specific heat of a solid varies a little at different temperatures, and even in the different states or conditions in which it occurs; another, that the atomic weights themselves, the second element in the calculation, are subject still to some uncertainty.

Hence we are led to infer, that in the six bodies in which the atomic weight is double what it ought to be in order to bring out a corresponding result, the ultimate atom may be only half what is generally assumed, or, in other words, that *the weight of the combining proportion is double that of the atom itself.*

The researches of Avogadro and Neumann gave additional force to this opinion, by tracing the same law to many compound bodies, those alone being compared together whose atomic constitution was similar.

Avogadro indeed has proposed a general formula* for calculating the specific heat of each class of compounds, the correctness of which however has been verified, comparatively speaking, in a few instances only, and which even in these requires for its adoption that the atomic weights should in some instances be halved, and in others undergo a still farther subdivision.

Without concerning ourselves therefore with this, which will be regarded probably as a still greater complication of a subject in itself rather intricate for an elementary treatise, and referring my readers for further particulars to the original Memoirs translated from the Italian† into the *Annales de Chimie*‡, I will pass on to a mere statement of the results he obtained, in the accuracy of which his agreement with the independent observations of Professor Neumann of Königsburg is calculated to give us increased confidence.

These results shew, that the same correspondence between the atomic weights and the specific

* The law is as follows: 'The specific heat of an atom of a compound is equal to the square root of the number expressing the atoms which concur to form this compound, whether it be a liquid or a solid, taking for unity the specific heat of any one of the simple bodies in the same condition.'

† *Memorie della Soc. Ital. de Scienze resid. in Modena*, vol. XX.

‡ Vol. LV. and LVII., 2nd series.

heats, as in the case of simple bodies already noticed, prevails in salts, throughout the class of carbonates, as is exhibited in the following table, by which it will be seen, that the product of the specific heat, multiplied into the atomic weight, represents a constant quantity, or at least one so nearly the same, as to bring the results fairly within the probable limits of experimental error.

T A B L E.

	Specific heat observed.	Atomic weight.	Product of the two.
Carbonate of lime.....	0.2011	50	10.055
———— of iron.....	0.1819	58	10.550
———— of zinc.....	0.1712	64	10.956
———— of barytes ...	0.1078	100	10.780
———— of strontian ..	0.1445	74	10.693
———— of lead.....	0.0814	134	10.907
———— of lime and } magnesia (Dolomite) }	0.2161	46	9.940

and likewise amongst the sulphates ;—thus :

Sulphate of lime	0.188	68	12.784
———— of iron	0.145	76	*11.020
———— of copper ....	. 180	80	*14.400
———— of barytes	0.108	118	12.744
———— of strontian ..	0.136	92	12.512
———— of lead	0.085	152	12.920

For here too in 4 of the compounds the product approaches very nearly to $12\frac{1}{2}$, whilst in 2 only, marked *, is there any wide deviation from that number.

In accordance with the views which the above researches tend to suggest, M. Dumas admits, that the specific heat of a body is to be taken as an *index* of the weight of its ultimate atoms, every atom requiring the same amount of caloric to raise it to a given temperature.

He contends however, that their ultimate atoms need not be the same with those chemical atoms or molecules which enter into union one with the other, and that the latter may be supposed to consist of groups or assemblages of the former.

The following, therefore, may serve as a brief abstract of the views entertained by Dumas, which deserve the more to be pointed out to my readers, in order that they may perceive the distinction between them, and those stated in the former chapter, which represent the views originally put forth with respect to atoms, and even now perhaps more generally entertained concerning them.

And first, with respect to the mathematical question which stands on the threshold of the

subject, we are still equally at liberty to embrace the theoretical doctrine of a capacity for infinite division necessarily inherent in matter, or the more metaphysical and recondite hypothesis of Boscovich, who, as we have seen, deduced the primary qualities of all natural bodies from the existence of a number of ultimate points, destitute of all properties, save those of mutual attraction and repulsion, operating at certain distances, and obedient to certain laws.

But the present stage of experimental knowledge, whilst it leaves us thus free to speculate as before with respect to the intrinsic capacity of division, which may belong to the least conceivable portion of matter, as well as to the largest, affords at the same time grounds for the belief, that the Author of Nature has placed somewhere in the scale of minuteness a point, beyond which no natural force can carry division. Now a body, of whatever dimensions we may assume it to be, which is held together by a force superior to any which can ever be brought to divide it, we denominate an *atom*.

Their relative weights may probably be indicated by the specific heats assigned to the several substances which are regarded as aggregates of them.

With these atoms however Chemistry, strictly speaking, has no concern, but it is with groups or assemblages of them, held together by a certain coherent force which is proof against every other sort of attraction, that this science is conversant.

These assemblages of atoms, which perhaps should be distinguished by a separate name, but which M. Dumas denominates *chemical atoms*, uniting with each other in various amounts, produce combinations according to the law of definite proportions, and are mutually displaced through the operation of chemical affinities.

Lastly, by converting a body into gas or vapour, we separate it into other groups or particles, consisting of one or more of those between which chemical union takes place.

Whatever ultimately may be the fate of this hypothesis, it appears to me at least not liable to the objection which has sometimes been brought against it of doing away with the doctrine of atoms.

So long as the composition of bodies is admitted to be definite, so long as it can be shewn, that in all substances the combining proportions are such, as in each case of chemical union to present either the same quantities, or else others

so related, as mutually to bear some fixed numerical proportion, it seems evident, that there must lie at the root of them all an indestructible and indivisible particle, and that, whether we conceive chemical union to take place between single particles of each of these, or between several of them, the argument in favour of the existence of atoms, grounded upon the fixed proportions in which bodies combine, and on their uniformity of composition, as well as of properties, at all periods, and in all places, remains wholly unaffected.

CHAPTER VI.

ON ISOMORPHISM.

Form of the atoms—Notions on the subject entertained in ancient times—Two hypotheses in modern days proposed—Mitscherlich's doctrine with respect to isomorphism explained—and exemplified in the compounds of arsenic and phosphorus—Objections to the doctrine removed—Accordance of properties between isomorphous bodies not complete—How far similarity of form implies analogy of chemical relations—Isomorphism arises from a similar arrangement of the particles—and may be adopted as the groundwork for a classification of simple bodies.

In the preceding chapter it was shewn, that the law of definite proportions, extending as it does to all combinations that take place between one body and another, naturally suggests views with regard to the intimate constitution of matter, which, if not identical with, are at least analogous

to, those entertained by the ancients, since whether we choose to adopt the simpler doctrine of ultimate atoms, as was proposed by Dalton, or prefer that modification of it which we owe to Prout and Dumas, a limit to the actual divisibility of matter is alike supposed.

So far then the speculations of the ancients and the deductions of the moderns appear to coincide, but here the similarity terminates, for when we inquire further into the notions of the former with respect to the particular constitution, form, and properties of their atoms, and compare them with those which prevail at present, a divergence of opinion between the two is immediately perceived.

Democritus for instance, and after him Epicurus, attributed, as we have seen, all the qualities of matter either to the shape, the size, or the weight of their component particles, and supposed the mere motion, that was communicated to them in the act of descending through space, sufficient to bring about all the changes which occur naturally, or are produced by art.

According to them therefore the particles were in actual contact one with the other, at least at certain parts of their surface, since the very form and consistency which belong to solid bodies re-

sulted from the shape of their particles, which was such as to cause their mutual entanglement, and thus to produce their cohesion.

It is almost needless for me to state, that no such notions are entertained at present, the immediate cause which brings about chemical changes being considered not to be in its essence a mechanical one, even although it be affected by mechanical influences, but to be the direct result of two forces, namely Attraction and Repulsion.

Nor can the texture of a solid be in any way ascribed to the entanglement of the points or angles of the respective atoms, since we have the strongest reason for believing that the latter never *touch*, but are kept apart one from the other even in the most compact bodies through the agency of heat.

With respect however to the form of the particles of matter two hypotheses have been entertained in modern times, the former of which supposes that the primary form belonging to a body represents that of its ultimate atoms; the latter maintaining that it has no necessary resemblance to them.

Thus, according to the former view, a rhomboedral crystal will be made up of a number of little

rhomboids piled up one upon the other, and if the order of accumulation be not the same on all its sides, other secondary forms that can be deduced from the primary one may be readily understood to be the result.

This hypothesis however, plausible as it may seem, is entirely overturned by the fact already alluded to, of the occurrence in nature of bodies having two or more modes of crystallization nowise related, as it is impossible to imagine, that the ultimate atoms of a substance, chemically the same, can pass from one form to another in this manner.

Let us turn then to the second hypothesis, which assumes, that the crystals of a body are all composed of particles of the same shape, piled up in different ways one upon the other.

This was the view adopted by Dr. Wollaston, who, in his Bakerian Lecture for 1813, endeavoured to shew, that the octaedral and tetraedral figures are such, as might be naturally assumed by a number of perfect spheres brought into the nearest possible contact one with the other. The obtuse rhomboid, of which a numerous class of solids found in nature are modifications, might have arisen from spheroids, the axes of which should be their shortest dimension, whilst, if they

were *oblong* instead of *oblate* spheres, hexagonal prisms would result from their mutual attraction, the centres of bodies of such a figure approaching nearest to each other, when their axes are parallel, and their shortest diameters in the same plane. A cubical figure would result, if two sets of spherical particles, all of the same size, and equal in number, were to combine in such a manner, that every particle of the first kind should be equally distant from all the surrounding ones of the second kind, and all the adjacent particles of the same description equidistant from each other. Hence a cube ought, as it should seem, to be the form assumed by a compound consisting of two ingredients possessing each an equal number of atoms, whilst the octaëdron or tetraëdron would be that which a body composed altogether of the same particles would affect.

Now it is curious, that the metals, which we have more reason to regard as simple than the generality of other bodies, crystallize in an octaëdral form, though we are at the same time cautioned against relying upon such a principle, by observing that many compounds, as fluor spar for example, possess the same evidence of simplicity*.

* See also a Memoir by the late professor Daniell on this

Ampere, in his Memoir in the *Annales de Chimie* (vol. 90), has simplified still further this hypothesis, and has unquestionably shewn the possibility of building up any conceivable form by a particular arrangement of spherical atoms, leaving it however still a problem, why in each particular case the spheres should arrange themselves always in a certain determinate order.

Dimorphism may thus arise, where, through the influence of temperature or other causes, the forces that attract the molecules in a certain manner shift their position, and the amorphous condition of bodies may proceed from the clustering together of the atoms without any definite order, owing to the rapidity with which they passed from a liquid to a solid condition.

The atoms of bodies therefore may be imagined to consist of spheres endowed with certain forces of polarity and of chemical affinity, the former force producing the various forms which crystallized bodies affect, the latter bringing about combinations between one substance and another.

subject, contained in the *Journal of the Royal Institute* for 1831. It in general confirms the views given in the text, except that he explains the cubical form of crystals differently from Dr. Wollaston.

But it may still remain open to inquiry, whether these forces, the first of which determines cohesion, as the second does chemical union, are to be regarded, like gravitation and the other physical properties of matter, fixed and unalterable, since upon the determination of this question must depend, whether they are to be set down as inherent equally in each particle of matter, as they are in the entire mass.

With respect to polarity however, this point appears to be set at rest by the occurrence of dimorphism, which indicates, that the crystalline form of a body is not always determined by any unalterable property appertaining to its component atoms.

And with reference to the chemical affinities which belong to a body in the aggregate, there are many facts which seem to shew, that these arise out of the arrangement of the particles, and are not the unalienable attributes of the particles themselves.

In illustration of this, it will be now proper to allude to the grand discovery of Mitscherlich, which, in its bearings on the subject we are discussing, ranks next to that of Dalton in the scale of importance, and which, whilst it suggests on the one hand, that one of the conditions at least,

upon which a similarity of crystalline form depends, may be a correspondence in the number of the component atoms, indicates, on the other, that the chemical nature and relations of the latter are greatly influenced by the mechanical structure of the mass which they form by their union.

It had been remarked in the first place, that many mineral bodies having one of their ingredients in common crystallise alike, and that this occurred, in some cases when the acid, in others when the base was identical.

Thus the carbonates of lime, magnesia, iron, zinc, &c. deviate very slightly from the same standard in point of external form, and in like manner, a nearly exact correspondence may be traced between the salts of arsenious and arsenic, and those of the phosphorous and phosphoric acids.

It has been further remarked, by Gay-Lussac in the first instance, with respect to the different kinds of alum, and by Beudant, Mitscherlich, and others in the case of a variety of other compounds subsequently, that salts which crystallize alike are able to replace each other without altering the structure of the mass, and that when once intermixed they scarcely admit of being separated.

Thus the different kinds of alum, that with soda, with ammonia, and even with chrome, and with iron, are found alternating in layers, or else confusedly intermixed, in the same crystal, with the ordinary kind which owes its characteristic form to the presence of potass.

Substances thus related Mitscherlich denominated *isomorphous bodies*, regarding this similarity of form, as an evidence of similar atomic constitution, and as an index of other corresponding analogies in their respective chemical relations.

This latter fact was established by many striking examples.

The acids of arsenic and of phosphorus, for instance, form salts which crystallize alike, and their respective bases not only correspond in a more general way in acquiring acid properties with oxygen, forming gaseous compounds with hydrogen, &c., but also in the unusual proportions in which oxygen and hydrogen enter into union with them, phosphorous and arsenious acids containing 3 atoms, phosphoric and arsenic 5 atoms of the former principle, and arsenuretted as well as phosphuretted hydrogen 3 atoms of the latter.

The corresponding arseniates and phosphates also agree in taste, and in the degree of force with which they retain their water of crystallization.

If we extend our inquiries to the metal antimony, the analogy in some respects is still more striking, oxide of antimony being composed of 3, antimonious acid of 5 atoms of oxygen to 1 of base; hydrogen, in the proportion of 3 atoms to 1 of the metal, constituting a gas similar in its properties to arsenuretted hydrogen, and arsenious acid being capable of taking the place of oxide of antimony in the medicinal preparation called tartar emetic.

Here, moreover, we may seem able to trace back the cause of this similarity of structure and properties one step further, the metals arsenic and antimony both crystallizing in the form of an acute rhomboedron, although we are cautioned not to lay too much stress upon such a fact, by finding that the analogous body phosphorus crystallizes in regular dodecaedrons.

That a similarity of crystalline form is in many instances coincident with an analogy in chemical properties, has been thus sufficiently established by the researches of Mitscherlich, confirmed as they have since been by other independent observers, but to what extent this principle admits of being generalized, still remains open to inquiry.

It must be confessed indeed, that some of the

apparent exceptions to the law laid down have been very satisfactorily removed by the progress of discovery, and have thus tended, when rightly interpreted, to corroborate its truth.

Thus Professor Marx of Brunswick instanced a compound of arsenic acid with soda, which crystallizes differently from the compound of phosphoric acid with the same alkali, and alleged it as an objection to the doctrine of isomorphism.

This discrepancy, however, was subsequently shewn by Professor Clarke of Aberdeen to arise from a difference in the chemical constitution of the two bodies, the arseniate being found to contain only 15 atoms of water, whilst the phosphate contained 25.

Nor was this all, for Professor Clarke likewise brought forwards a striking confirmation of the correctness of Mitscherlich's doctrine, by discovering a new salt composed of phosphoric acid and soda with 15 atoms of water, the crystalline form of which almost exactly corresponded with that of the arseniate alluded to, so that the objection previously urged against the system was converted into a most triumphant argument in its favour.

The same explanation as that offered by Professor Clarke may be extended to certain anomalous cases pointed out in the earlier stages of

the discussion by the Abbé Haüy and others, who specified several salts consisting of the same acids with two isomorphous bases which crystallized differently, for here too a material circumstance had been overlooked, namely, the presence of different proportions of water.

Thus the sulphate of copper is isomorphous with the sulphate of manganese, because they respectively consist of $1(\dot{R}^* + \ddot{S}) + 5 \text{ Aq.}$ but not with the sulphate of iron or of cobalt, on account of the different proportion of water in these latter, which may be represented by the formula $1(\dot{R} + \ddot{S}) + 7 \text{ Aq.}$

Another objection started to the theory of isomorphism proceeded from certain exact crystallographers, like Mr. Brooke, who have shewn, that bodies regarded as isomorphous do not after all crystallize in precisely the same forms.

Thus, in the rhomboedral crystals of the carbonates of lime, magnesia, iron, manganese, and zinc, the angle of inclination at the extreme edges of the rhomboid varies from 101,5 to 107,40, and in a similar isomorphous group, consisting of the carbonates of baryte, strontian, and lead, with which is associated the prismatic form of carbonate

* The symbol R is intended as a general expression for any base or radical.

of lime, namely, arragonite, the angles vary in the different members as much as 2 degrees.

Nor will this appear surprising, now that we learn from the researches of Mitscherlich, that the very same substance undergoes a change in the angles of its crystals through an augmentation of temperature.

Thus, when carbonate of lime is heated from 32° to 212° , the linear expansion in the direction of the principal axis is 0,001968, whilst in that of the horizontal axes there is a contraction equal to 0,0056, so that the obtuse angle of the rhomb, which at 50° Fahr. is equal to $105^{\circ} 4''$ becomes more acute by $8\frac{1}{2}$ deg., and the acute angles, which are $74^{\circ} 54''$, become more obtuse in an equal degree.

Hence, in order that an exact identity in crystalline form should be maintained between two bodies, it would be requisite, that they should be influenced alike by heat, in short, that they should agree in all their leading physical characteristics, which can hardly be expected, unless they were not only allied to each other, but identical.

If in the external form of isomorphous bodies no entire uniformity exists, neither is there an absolute correspondence in their chemical relations.

Even in the most perfect instance of the kind

known, namely, the group which comprises arsenic, phosphorus, and antimony, there is no counterpart in the two former to the antimonious acid, which contains 4 equivalents of oxygen, or to the compound of antimony with 4 atoms of sulphur.

Neither does the arsenic acid, notwithstanding its close analogy to the phosphoric, form with water those three distinct acids, which the latter does under the same circumstances.

It has been proposed by some writers, who aim at greater precision of language, to employ the term *plesiomorphism*, where the resemblance between two bodies in external form is not regarded as complete, but it seems objectionable to distinguish by a separate name two sets of cases, which will probably be found to depend upon the same principle, and may hereafter constitute links of a common chain, since it would perhaps be difficult even now to point out two bodies which are exactly isomorphous.

Another source of perplexity is, the fact, that many, and perhaps all, substances are capable of assuming two distinct forms nowise related to each other.

Thus carbonate of lime, as has been already stated, crystallizes, sometimes in a rhomboedral,

sometimes in a prismatic form, and yet its chemical properties continue in both the same.

But without attempting to elude the theoretical difficulty in which such a fact involves us, it may be stated, that the law of isomorphism even in these cases is verified, where we find, that as carbonate of iron and carbonate of lead are also dimorphous, one form of each of these metallic salts agrees with calc-spar, the other with aragonite.

Probably time will reveal similar analogies in other members of the same series.

But whilst we admit that similarity of crystalline form affords a presumption in favour of a relationship or analogy in other respects between two compounds, it will be perceived, that this presumption is stronger or weaker, in proportion to the greater or lesser complexity of the crystalline form assumed.

Where the system to which the crystal belongs is of the most simple kind, or that in which the axes are all equal, whether it be the cube, the octoedron, or dodecaedron, the inference from the fact of agreement in figure, in favour of similarity of properties, is very weak indeed.

Thus, as has been already remarked, bodies the

most dissimilar, such as the metals, fluor spar, alum, &c., possess in common the same external figure.

Where, on the contrary, the crystallization is of a more complex nature, we must suppose a greater accordance of atomic structure in order to produce it, and from this may result a more complete analogy in its relations to other bodies.

Another caution applies to the assumption which has been too hastily taken up on theoretical grounds, that isomorphism in the compounds necessarily implies isomorphism in the elements from which they are derived.

If it be considered, that we are as yet far from having arrived at a knowledge of what the real elements of matter may be, and that we adopt those which are treated as such in a manner provisionally, until they have been decomposed into other simpler forms, it would indeed be surprising, on any theory, were this correspondence often detected, and if I have given an instance where a similarity of external form in the compound is traceable to its elements, another has been already brought forwards where no such accordance exists. Of the latter description, however, many other examples may be cited.

Thus carbonate of lime and nitrate of potass

are isomorphous, but we are not therefore to infer, that carbon is isomorphous with nitrogen, or calcium with potassium.

Sulphur and selenium also, like phosphorus and arsenic, assume a different crystalline arrangement, although their compounds are isomorphous.

Thus, so far as our knowledge of this obscure subject at present extends, we should be tempted to infer, that the form of the ultimate molecules of matter may be in all cases identical, and that the similarity in this respect which compound bodies often affect, and which, when coupled with certain analogies in other respects, we designate isomorphism, arises out of a different arrangement of particles essentially the same in figure.

If, as Davy has shewn, that which by itself exhibits no signs of electrical excitement, may nevertheless be rendered either positive or negative by the approach of a foreign body, and when in that condition exhibits properties which it had not before, it is conceivable, that the particles may influence each other in different ways, so as to bring about a great variety of new properties, according to the particular mode of their collocation or grouping.

This inference may appear to be strengthened,

by finding that in some instances 2 or 3 atoms of a particular substance will take the place of 1 atom of another, without affecting its crystalline form.

This is said by Scherer to be the case with water, 2 atoms of which are isomorphous with 1 of oxide of copper, and 3 with 1 of oxide of iron, of oxide of manganese, and of magnesia;—probably also with 1 of oxide of nickel and of zinc.

It is in this way that the relation of form subsisting between certain minerals, such as cordierite and aspasiolite, serpentine and olivine, may according to this mineralogist be accounted for.

Two atoms of copper appear also to be isomorphous with one of silver, the subsulphuret of the former, and the sulphuret of the latter corresponding in form ($\text{Cu } 2 \text{ S} = \text{Ag S}$).

The same is the case between the perchlorates and the permanganates, though the former consists of $\text{Cl } 1 + \text{O } 7$, the latter of $\text{Mn } 2 + \text{O } 7$.

1 atom of arsenic too appears to be isomorphous with 2 atoms of sulphur.

Yet, although we are led from these facts to conclude, that isomorphism arises from a similar arrangement of the molecules of matter, rather

than from any greater resemblance between their ultimate atoms, than between those of others presenting no such analogies in form and properties, the correspondence itself must be taken as a fact, establishing a certain relationship or resemblance between the bodies which present it, and therefore may fairly be considered a proper groundwork for a natural arrangement of chemical elements, in which light it has been presented in Professor Graham's excellent Elements, as well as in other recent Treatises on Chemistry.

CHAPTER VII.

Same subject continued—Isomeric bodies—accounted for—1st by a difference in the degree of aggregation—2ndly by a difference in the arrangement of the particles—Law of substitution considered—Theory of chemical types—and of compound radicals.

IN the preceding chapter it was shewn, that many bodies display with reference to each other a great correspondence in crystalline form, and that, where this is the case, a certain analogy in respect to their properties, as well as with respect to the proportions in which they combine with others, may in general be traced out.

This accordance, however, between chemical properties and crystalline form, proves only that the cause, whatever it may be, which determines both, is probably identical.

There is, however, another set of facts now become familiar to chemists, especially since or-

ganic substances have attracted so much of their attention, which may suggest the inference, that the distinctive properties of bodies themselves flow as much from the mechanical arrangement of their particles, as from any inherent difference in the particles themselves—not indeed that chemical action is to be confounded with mechanical, but that the chemical affinities, which subsist between bodies, grow in some way or other out of the juxta-position of the particles which compose them.

At first sight nothing would seem more obvious, than that aggregates made up of the same number of atoms of two or more bodies should give rise to the same products; or, in other words, that there should be only two possible causes to which differences between one compound and another could be referred, namely, either their having been formed of essentially different elements, or of the same elements combined in different proportions.

Within the last thirty years, however, a multitude of facts have come to light, which go to prove, that bodies, apparently possessing the same precise atomic constitution, may differ materially in their properties, so as even to belong to a different class altogether.

The most beautiful illustration of this fact, was perhaps that offered by Liebig, in his discovery of the mutual conversion of cyanuric acid into the hydrated cyanic acid, and the latter again into cyamelide, as we have here three bodies, most contrasted in their properties, and even in their physical condition, produced by mere difference of temperature, without the abstraction or addition of any ingredient whatsoever*.

Such instances, however, have now become so common, as to have rendered it necessary to invent the term *isomeric* to distinguish bodies so circumstanced, namely, those which, although endowed in different properties, consist of equal parts or proportions of the same elements.

But, as it would be unphilosophical to suppose an effect to arise without a cause, chemists have

* Cyanuric acid, a compound of cyanogen and oxygen, produced amongst other ways by heating urea, a compound of it and ammonia, is a solid, colourless, inodorous body, crystallizing in oblique rhombic prisms, and soluble in 24 parts of boiling water. Heat converts it into hydrated cyanic acid, a clear transparent liquid, having a strong odour, highly caustic properties, and considerable volatility, which however decomposes spontaneously into cyamelide, a white porcelain looking solid, insoluble in water, dilute acids, and alcohol.

naturally laboured to discover what other differences, independent of composition and relative proportion, can be conceived to subsist between two bodies thus distinguished.

Now in some cases, the discrepancy between them appears to arise, from the different degrees of condensation which the ingredients have undergone.

Thus, at least four compounds of carbon and hydrogen in equal atomic proportions have been recognized by chemists*.

The first of these is olefiant gas, in which two volumes of the vapour of carbon and two of hydrogen are condensed into one volume.

The second, is the most volatile of the liquids†, obtained by Faraday from oil gas that had been condensed to render it portable, in which four volumes of each ingredient are condensed into one.

The third is cetene, an oily liquid described by Dumas, in which sixteen volumes of each are

* Dr. Thomson (System of Chemistry, vol. I. p. 135, 1831) also points out the existence of a gaseous hydrocarburet, only as yet detected in combination with chlorine, in which no more than 1 volume of each ingredient is condensed into a single volume.

† It boils at 32°, but is liquid at 0.

condensed into one. And to this the same chemist adds an hypothetical substance called methylene, in which he calculates, that one volume only of each is condensed into the same compass.

In these cases then, the difference of properties may be explained by the different degrees of proximity into which the particles are respectively brought, although the cause, which determines them to prefer the one condition rather than the others, is still involved in mystery.

Dr. Prout* has suggested, that if we adopt his supposition, as to combinations taking place, not between the ultimate atoms of matter, but between certain groups of atoms; if we assume also, that groups of various amounts, though always mutually related one to the other in point of number, have a tendency to combine with the atoms, or groups of atoms, of certain other substances; and if we imagine, that the chemical properties of the mass are modified by the number of ultimate atoms clustered together in the same group, the different properties of isomeric bodies may admit of a plausible explanation.

"Thus," to use his words, "the self-repulsive molecule of water on entering into combination,

* See his Bridgewater Treatise.

is often found to be divided into two or three (perhaps more) parts. Now as the division of an ultimate atom would imply a contradiction, we must conclude, that the molecules of oxygen and of hydrogen are much more compounded than is commonly represented, and must each of them contain at least three component or sub-molecules. Hence the self-repulsive molecule of water will consist of at least nine component sub-molecules, (viz. three of oxygen and six of hydrogen,) which we may suppose to be associated—in the first place the hydrogen with the oxygen *chemically*—and afterwards the three sub-molecules of water with one another, *cohesively*, so as to constitute one spheroidal molecule, in a manner, that with a little ingenuity it would perhaps not be difficult to represent mechanically. Now it is very possible, that the chemical properties of a sub-molecule of water, or of any other substance, may differ from that of the molecule itself; or to express it in other language, that a group of 100 atoms, for example, should possess properties somewhat different from one consisting of 50, or of 25, and hence that the bodies compounded of the former may vary from those formed out of groups in which either of the latter proportions prevail.”

But there is a large class of isomeric bodies to which this explanation cannot be extended; as for instance, where two or more substances, identical in point of composition, exist in the same state, either as solids, liquids, or gases.

In these cases, we are led to attribute the difference to an alteration in the arrangement of the particles which each body contains, just as two buildings may consist of the same number of bricks, identical in figure and size, and yet by the different modes in which they are piled up, the form and uses of the aggregate may be as distinct as possible.

The analogy, however, does not admit of being carried out into its details.

In the case of the buildings, the differences in structure are perceived to spring from the mechanical arrangement of the bricks composing them, whilst in that of two isomeric bodies, the collocation of the particles can only be supposed to affect the properties of the resulting body, by inducing new affinities in each other respectively, just as the approach of two heterogeneous bodies renders each one for the time electrically excited.

This conclusion seems also to be supported by those principles of combination which have been found to prevail amongst organic bodies, and

which, under the name of the Law of Substitutions, Dumas more especially has insisted upon, and made the groundwork of the Theory of Chemical Types, which he above all others has brought so prominently forward.

The law of substitutions, indeed, seems to bear about the same relation to the doctrine of chemical types, which the law relating to chemical equivalents does to the atomic theory, and therefore requires to be explained in the first instance before entering upon the latter.

Law of Substitutions.

When inquiries began to be instituted into the nature of bodies derived from or connected with the two kingdoms of organic nature, a much greater complexity of composition was observed to belong to them, than in those compounds of mineral origin which had been previously investigated.

The latter had been found to consist, either of two elements, in the proportion of 1 atom of the first, to 1, 2, 3, or some other limited number of atoms of the second; of combinations of these primary compounds in the same simple ratio; or, lastly, of compounds produced by the association of two of those last mentioned one with the other.

Under the first head we rank the oxides, chlorides, sulphurets, acids, and the like; under the second, the salts formed by the union of an acid with an oxide, one sulphuret with another sulphuret, &c.; under the third, the combinations of two salts one with the other, as sulphate of alumina with sulphate of potass in the case of alum.

Even this classification may admit of being still further simplified, if we adopt the binary theory of salts which will be hereafter explained.

Now the general characteristic of this order of combinations seems to be, that the respective ingredients are strongly contrasted, both in their chemical properties, and in their relations to electricity; that the union may take place directly when the two substances are brought into juxtaposition; and that the force which binds them together is such, as not to be overturned except by some powerful influence, either of heat or of chemical affinity.

The very reverse of all this seems to prevail amongst organic bodies in general.

The number of atoms of each ingredient is here often very considerable, and in general three, and even sometimes four or more elements, are associated together in the same compounds.

Nor are the elements that combine necessarily antagonistic, and accordingly, when this is not the case, they cannot be made to unite together *directly* in the way we have supposed, but are formed through the medium of reactions, either natural or artificial, in which, existing combinations being broken up, the ingredients that composed them are presented to each other in what is termed their *nascent state*.

These compounds are also much less stable, being decomposed by very slight causes, and, as they are far more numerous than the former, so are they separated one from the other by much finer shades of distinction.

Now, it is in compounds of this latter description, that Dumas and others have traced the law of substitution which I am about to explain, although, strictly speaking, it may be doubted, whether the same might not be extended to all chemical changes between compound bodies whatsoever.

When, for instance, sulphuric acid decomposes nitrate of potass, what is it, it may be asked, but a substitution of \ddot{S} for \ddot{N} , together with the production of a salt analogous to the one destroyed, and even when the same acid unites directly with potass, may not the elimination of water from

the latter in the same ratio lead to a like conclusion?

There is, however, this distinction between the two cases; namely, that whereas in inorganic bodies the ingredients that combine are strongly antagonistic in their properties, so the body, which takes the place of another in an existing combination, must belong to the same class, or possess similar relations to electricity.

Thus, sulphuric acid may be substituted for any of the other acids, but not for an oxide or a chloride, and chlorine may take the place of iodine or bromine, but not of hydrogen.

Moreover, the new compound, formed by the substitution of one ingredient for another, in the case of inorganic bodies, often bears a much more remote analogy to the original one.

Thus, when barytes is substituted for soda already in union with sulphuric acid, sulphate of baryta is produced in the place of sulphate of soda, a substance as different from it as one salt can be from another.

But in the organic kingdoms we find, not only sulphur and phosphorus, but even chlorine, replacing hydrogen, and yet the resulting body may still retain a very near analogy to the one from which it was obtained.

In order to make my meaning clearer, I will bring forward a few examples, in which this remark appears to be borne out.

Sulphuric ether appears from its analysis to be a compound of



Now the liquor produced by the Dutch chemists from olefiant and chlorine gases consists of



so that chlorine would seem here to have taken the place, not only of the oxygen, but also of 1 atom of the hydrogen, present in ether. Nevertheless, there is such a resemblance between the two bodies, as to volatility, inflammability, and general properties, that the name of chloric ether has not been inaptly applied to the Dutch liquor in question.

Here then, the presence of the chlorine in the same proportions as those of the two elements removed, does not appear to affect materially the qualities of the product.

The next example we shall give is the more striking, because the second compound is directly derived from the first through the agency of chlorine.

Vinegar, as strong as it can be procured, always contains 1 atom of water, and in this

state its composition may be regarded as follows:



Now this liquid, exposed along with dry chlorine to the action of the sun's rays, is converted into an acid called the chloracetic, consisting of $\text{C}_4 \text{Cl}_3 \text{O}_3 + \text{HO}$, so that Cl_3 has taken the place of H_3 . Yet there is no fundamental difference between the two acids, and their saturating power is exactly the same, notwithstanding the introduction of this new element.

Thus too, as by the action of oxidizing agents on alcohol ($\text{C}_4 \text{H}_5 \text{O} + \text{Aq.}$) we produce aldehyde ($\text{C}_4 \text{H}_3 \text{O} + \text{Aq.}$), owing to the abstraction of H_2 , so in like manner by the action of chlorine upon alcohol, we produce chloral, which consists of $\text{C}_4 \text{Cl}_3 \text{O} + \text{Aq.}$, aldehyde being first produced, and afterwards its 3 atoms of hydrogen being replaced by 3 of chlorine, notwithstanding which these two bodies are very analogous in their chemical relations.

Another striking instance of parallelism is given by M. Laurent, between a compound called isatine, derived from the oxidation of Indigo, and two substances called *chlorisatine* and *bichlorisatine*, produced from it by the substitution either of 1

194 . *Substitution of elements without material*

or 2 atoms of chlorine for 1 or 2 of hydrogen.

Isatine being composed of ..	C ₁₆ H ₅	NO ₄
Chlorisatine	C ₁₆ H ₄ Cl	NO ₄
Bichlorisatine	C ₁₆ H ₃ Cl ₂	NO ₄

Now between isatine and the first of these an almost entire correspondence exists, the colour, crystallisation, volatility, solubility in water, and saturating power, being almost identical, nor is there a much greater difference in the second case, where 2 atoms of chlorine replace 2 of hydrogen.

The last instance will serve to shew that no considerable change of properties need result, even when more than 1 atom of an ingredient belonging to the original compound is replaced by another, although that other be as contrasted with it, as chlorine is with hydrogen.

M. Laurent, however, has illustrated this latter principle most strikingly, in the series of combinations which he has brought about from a product obtained during the distillation of coal tar, which Dr. Kidd, its discoverer, denominated naphthaline.

Naphthaline is a compound of C₂₀ H₈, but in which it would appear, that any number of its

atoms of hydrogen admits of being replaced by an equal number of atoms, either of chlorine, of bromine, or of nitrous acid.

As, however, different compounds are produced, according to the number of atoms removed, and that of the other bodies substituted, Laurent has proposed an ingenious device for the purpose of distinguishing them.

Thus, the initial syllable of the *replacing* substance is prefixed, and the number of atoms *replaced* is denoted, by introducing into the final syllable of the name one or other of the five vowels of the alphabet, in their natural order of sequence.

If the replacing substance be in the proportion of 1, or a multiple of 1, to each particle of the original compound, the termination *se* is employed; if in that of 1, to every two particles, or in that of 2 to 3, then the termination *ne* is adopted.

Thus, supposing the replacing body to be chlorine, chlonaphthase will designate a compound derived from naphthaline, in which 1 atom of this element has been substituted for 1 of hydrogen; chlonaphthese, when 2 atoms are so replaced; chlonaphthise, where 3; chlonaphthose, where 4; and chlonaphthuse, where 5.

But supposing more than 5 atoms of chlorine to have been introduced, we proceed, by adding a fresh syllable, and returning again to the letter *a*.

Thus, chloronaphthalase is a compound in which 6 atoms of chlorine has taken the place of 6 of hydrogen, and chloronaphthalise one in which the chlorine has entirely superseded the hydrogen.

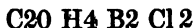
Supposing a combination to exist in which the proportions were as follows :



or 2 atoms of naphthaline, in 1 of which an atom of hydrogen is replaced by chlorine, the proper term would be chloronaphthane, and so with the rest.

Where the replacing body is bromine, the syllable *bro* is prefixed, with a vowel indicating the number of its replacing atoms, and when the hydrogen is partly replaced by it, and partly by chlorine, the element first introduced has the precedence.

Thus, *bromechlonaphthose* indicates a substance composed of



in which the 2 atoms of bromine were first in-

troduced, and in like manner *chlorebronaphthose*, one consisting of the same ingredients, but in which the atoms of chlorine were introduced before those of the bromine.

There is still a further complication, for it may happen, that the bromine is in the proportion of $1\frac{1}{2}$ atoms, and the chlorine in that of $2\frac{1}{2}$, in which case the term *bromenchlonaphthose* has been adopted by Laurent to indicate this difference.

The compounds in which the hydrogen is replaced by nitric acid are denoted on the same principle. Thus we have

Ninaphthase ... $C_{20} H_7 O_4 N_1$,

Ninaphthese ... $C_{20} H_6 O_8 N_2$, &c.

One can readily understand, what a vast variety of combinations might be formed out of naphthaline, by ringing the changes upon these several atoms—but this by no means exhausts the subject, for in many cases Laurent has found, that in the naphthaline series several isomeric compounds exist, in which the same elements are combined in exactly the same proportions.

Thus he describes no less than 7 known cases of chlonaphthese,

$C_{20} H_6 Cl_2$,

198 *Several different substances produced, where*
obtained either by distinct methods, or by
slight modifications of the same mode of ma-
nipulating.

These are respectively distinguished, by at-
taching to each a different letter of the al-
phabet.

Thus chlonaphthese A, C, AD, E, F, X, and Y,
designate a series of bodies, all composed of
C20 H6 Cl2, which nevertheless each possess
some peculiar properties, as may be seen by the
following Table.

Distinctive characters of the several kinds of chlonaphthese.

	A	C	AD	E	F	X	Y
Form	Liquid.	In needle-shaped crystals, angle 112.86.	In needles 122°.	In needles 94°.	In tables 103°.	Liquid.	In laminae when sublimed.
Melting point		50°.	28 to 30°.	31°.	100°.		95°.
With chlorine	Forms liquid chloride of chlonaphthese, changed into chlonaphthos A by potass.	Forms solid chloride of chlonaphthese.	Forms chlonaphthese AC.		Forms chlonaphthone in laminae.	Forms liquid chloride of chlonaphthese, changed by potass into chlonaphthos E.	
With bromine		Forms bromide of chlonaphthese.	Forms chlonaphthos A.		Forms chlonaphthos B.	Gives a liquid.	

200 *Different substances produced according to*

There are also 6 known combinations corresponding to the formula of chlonaphthise, 4 to that of chlonaphthose, &c., besides 2 similar combinations of bromine, and 1 containing 2 atoms of chlorine and 2 of bromine.

Now, whilst the former part of the researches above recorded reveals to us the unexpected fact, that the composition of a body may undergo a material change, without any corresponding one taking place in its nature and relations to others—the latter affords examples of one equally perplexing, namely, that bodies similarly constituted may nevertheless differ in their properties, although in their physical condition alike.

Laurent's ingenuity, however, has devised an expedient for accounting even for this difficulty.

As the preceding facts would seem to indicate, that the properties of a body depend rather upon the *arrangement* than upon the *nature* of its component parts, it is suggested, that the influence of the body substituted may differ, according to the position occupied by the particle which it replaces.

We have seen in the case of naphthaline, that 20 atoms of carbon are united with 8 of hydrogen, and that any one of these is liable to be displaced.

Now it is conceivable, that as their respective atoms occupy different places in the compound which they contribute to form, the dislodgment of one may be attended with different results from that of another.

Thus, in accounting for the different kinds of chloronaphthese, we may suppose hydrogen, No. 1 and 2, displaced in the first, No. 3 and 4 in the second, No. 5 and 6 in the third, No. 7 and 8 in the fourth, No. 1 and 3 in the fifth, No. 1 and 4 in the sixth, and so on, according to which hypothesis, there might be as many distinct compounds, as are equivalent to the changes that may be rung upon this number of atoms.





Ample scope is thus given to the probable formation of a vast number of distinct substances derived from the same compound, all the various proportions in which chlorine enters into the composition of the naphthaline series giving rise to several, except the last, chloronaphthalise, where, as all the atoms of H are replaced by Cl, only one such compound would seem possible.

The above may be taken as a sample of a large assemblage of facts brought together by the labours of modern chemists, which tend to shew, that the chemical properties of bodies are in-

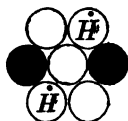
fluenced in a great degree by the disposition and arrangement of their particles.

It was this circumstance that led M. Laurent to suggest the doctrine of chemical types, which his eminent countryman, M. Dumas, has since contributed so much to recommend, by his brilliant eloquence, and by the authority of his name.

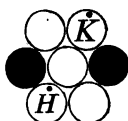
If we suppose a chemical compound to be made up of a certain number of atoms arranged in a definite order, it may be conceived, that although the loss of any one of the component atoms would involve the destruction of the entire fabric, yet, if another element be made to supply the place of that removed, the arrangement of the several parts may be maintained, and the chemical type preserved.

Thus, to take the simplest case, let us represent the composition of oxalic acid, together with that of the oxalate, and binoxalate of potass, according to the Daltonian mode of notation as revived by the French chemists, in which a sort of pictorial representation is attempted of the supposed compound, the symbol of carbon being , that of oxygen , of water , of potass ,

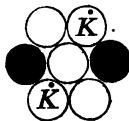
Oxalic acid.



Oxalate of potass.

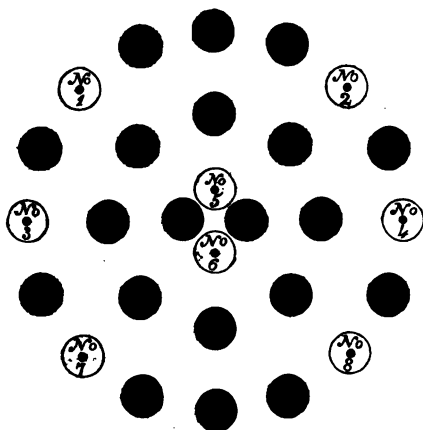


Bincoxalate of potass.



In like manner the composition of naphthaline, $C_{20} H_8$, may be represented by the following symbol, which will shew, into how many different positions chlorine and other bodies may be introduced in the room of the hydrogen displaced.

CHEMICAL TYPES.

Naphthaline $C_{20} H_8$ 

204 *Electrical condition of an atom determined*

Thus, when a chemical compound is exposed to the influence of re-agents, certain of its ingredients may be eliminated, either with or without the substitution of others.

In the first place, the chemical type will be preserved, and the properties of the body undergo only a slight alteration—in the latter it will be destroyed, and a new arrangement of the remaining atoms take place, accompanied by a much more fundamental change of nature.

The former result is illustrated by the production of chloracetic acid from acetic acid, and by the other examples cited above; the latter, when alcohol is distilled with sulphuric acid and oxide of manganese, in which case 2 atoms of hydrogen are removed from it by the oxygen of the manganese, without the substitution of anything else, and a new product is obtained, called aldehyde (*alcohol dehydratum*), possessing very different properties, and consisting of $C_4 H_3 O + Aq.$ or of alcohol, minus 2 H.

Thus, each of these bodies may be regarded as belonging to a distinct type, alcohol being connected with ether, &c., aldehyde being the nucleus, as it were, of a fresh set of combinations, amongst which acetic acid ranks as one*.

* See this illustrated in the Table at the end of the Chapter.

But how are we to account for the fact, that chlorine, an electro-negative body, takes the place of hydrogen, an electro-positive one, without altering the fundamental properties of the compound into which it enters as a constituent?

The theory of Davy, which suggests the difficulty, may perhaps afford us a clue to its solution.

We learn from it, that the electrical relations of a body are determined by its position, with reference to those to which it lies contiguous.

Thus nitrogen in nitric acid, is strongly negative, in ammonia, equally positive; sulphur is positive in relation to oxygen, but negative in respect to hydrogen.

Is not this dependent on the same principle, as that which Sir Humphrey Davy propounded, when he shewed, that the chemical affinities of many substances may be heightened or diminished at pleasure, by rendering that electrical condition, which belongs to them when in contact with those bodies for which they entertain an affinity, more intense, or by weakening it, by the contact of other bodies, possessing similar relations to electricity, but in a more exalted degree than their own?

The former case indeed is illustrated in the

common voltaic apparatus, where the zinc, which, if it be pure, or if it be amalgamated with mercury, remains unaffected by the acid, becomes acted upon by it, so soon as its electrical condition is rendered more intense, by being brought into connexion with a plate of copper plunged into the same menstruum.

The application of this principle to the protection of copper from the action of sea-water, is too well known to require to be dwelt upon on this occasion.

Some very curious facts have also been brought to light on this subject by Professor Schœnbein, of Basle, the substance of which was confirmed by Sir John Herschel and others.

These, from their general tenor, might lead us at first sight to believe, that the affinity of iron for nitric acid, instead of being inherent in the metal under all circumstances, was superadded to it by certain extraneous influences, its existence being dependent, upon the relations of the metal at the time to electricity, or on some other cause equally obscure*.

* Thus, if an iron rod be raised at one extremity only to a red heat, it will not be acted upon by nitric acid of the specific gravity of 1.35.

2. This immunity from the action of the acid may even be

Professor Graham, in his *Elements of Chemistry*, has attempted, by following up views which Faraday put forth with respect to the theory of the Voltaic Pile, to bring under the same general law the phenomena of chemical and of inductive affinity.

In the statement given of them, he has abandoned altogether the idea of electricity being concerned, remarking, that we have just as much right to attribute electrical attraction to chemical affinity, as chemical affinity to electrical attraction.

imparted to a second rod, if brought into connexion with the first.

Thus, if the heated wire be made to touch a second, and both be plunged into the same acid, neither will be acted upon. The same immunity is obtained, if an iron wire plunged into nitric acid be simply made to touch a wire of platina.

3. The same wire, if made the positive electrode of the galvanic battery, is not acted upon by the acid, though it transmits the galvanic current, and consequently decomposes the water present; whilst on the other hand it is vehemently attacked by the same acid, when in connexion with the negative electrode.

Hence the effect would seem to depend upon the electrical condition of the metal at the time being; but it is curious, that the same effect is produced, by simply immersing it for a few moments in acid, after which the action entirely ceases, and that it may sometimes be renewed by various mechanical methods, as by rubbing it with a copper wire, with glass, or in other ways.

Nevertheless, as it cannot be denied, that an attraction, however produced*, does take place between the masses of two bodies, at the very time when a chemical affinity is exerted between their particles; and as it has been assumed, that the former species of attraction is due to a particular fluid called electricity, it may render our views more intelligible, if we adopt the ordinary hypothesis, which regards electricity as the agent concerned in both series of effects.

Let us then suppose that every particle of matter possesses a definite amount of electricity, which in a passive state is equally distributed over its surface, but which is liable to be displaced, and determined to particular poles, by the contact or near approach of certain foreign bodies. This destruction of the electrical equilibrium is owing to what is called *polarity*, and it is therefore through its operation that ordinary chemical affinity arises.

But it may happen, that the disturbance of the balance of the two electricities is too slight in a particular instance, to render the resulting attraction between the particles of the body powerful enough of itself, to overpower the counteracting force of cohesion.

* See for an explanation of this, Faraday's Researches on Electricity, especially "On Specific Induction."

In such a case of course no chemical union will take place.

But if, at the same time that we disturb the equilibrium of the electric fluid in the particle alluded to, we also produce a similar polar condition in it, by bringing it into connexion with a body susceptible of an opposite electrical state to its own, as for example, when we bring together a piece of copper, and of amalgamated zinc immersed in an acid, which evinces no action upon the latter when alone, we may readily conceive, that the affinities of the metal for the solvent may be so far augmented, as to overcome the resistance which had before nullified its operation.

In this manner it may be possible to reduce to one and the same law, ordinary chemical attraction, and that augmented form of it which is produced by electrical induction; just as, to use Professor Graham's own illustration, attraction always exists between the magnet and steel, owing to the induced polarity caused in the latter when in proximity with the former, but this attractive force in the magnet is rendered more intense, by bringing its poles into contact with a bar of iron, as in the common horse-shoe magnet, in which it is well known, that the poles are both

rendered stronger, by being in juxtaposition with the opposite poles of the bar which connects them.

Thus, whilst modern discovery compels us to recognise a distinction between the physical properties of matter and their chemical ones, inasmuch as the former are essential and inherent, the latter connected in some unexplained manner with the number, proximity, and arrangement of their particles, and even induced in some cases by agencies manifestly extraneous, there is at the same time nothing to contradict the belief, that the conditions, on which depends the capacity of being affected in this manner, are in themselves as permanent, and subject to laws as fixed and definite, as those which seem more directly to belong to their constitution and nature.

After all, however, the Law of Substitutions, and the Theory of Chemical Types founded upon it, carry us but a small way towards understanding the mode in which organic compounds are constructed, and their relations to each other.

Returning to the old comparison of a building, the facts established with regard to substitution point out to us the architectural changes, which may take place without materially affecting the

character and uses of the edifice, and the theory grafted upon them may in like manner assist our power of comprehending, how such changes can be consistent with the integrity of the structure, by pointing out, that the new materials are only inserted where the old ones were before, and therefore that the form or *type* is preserved intact.

But in order to enable us to trace the progress of the building from its commencement, and to perceive the keystone upon which the superstructure rests, recourse must be had to the doctrine of Compound Radicals, which Liebig above all others has had the merit of unfolding.

It is surprising, that the theory of chemical types and that of compound radicals should ever have been regarded as opposed—for, instead of being inconsistent, they appear to give each other mutual support, the one supplying that which the other appears to have overlooked.

The former presents us with an ideal picture of the scientific edifice in its complete condition, the latter puts before us the several stages of its construction; the one points out the manner in which, by their arrangement even more than by their distinct nature, the materials conspire to the formation of an aggregate calculated for certain definite uses, the other renders more intelligible

212 *Compound radicals are in organic Chemistry.*

the manner in which the respective parts of so complicated a structure can hold together, and possess any degree of stability.

"Chemists," says M. Dumas, "have ascertained the existence in all mineral substances of a certain number of bodies regarded by us in the light of elements; they have determined that these bodies combine together, and that their combinations are able afresh to unite, so as to give rise to three orders of substances, acid, alkaline, and neutral, which they have succeeded in throwing together into a certain number of natural groups, by which means they are enabled to take a more comprehensive and philosophical, as well as a more simple, view of their nature and relations.

"One may easily understand, that with the 55 elements at present recognised, a series of combinations may be produced, equal at least in point of number to those which are known to exist in the mineral kingdom; but the difficulty was to apply the same method to the case of organic chemistry.

"There the number of distinct combinations recognised is not less great, nor is their character less diversified, and yet instead of 55 elements, we meet in the majority of known compounds with only three, or at most four.

“The great problem therefore is to explain, in accordance with the laws of mineral chemistry, the existence of that great variety of substances, which we derive from the animal and vegetable kingdoms, in which we rarely discover any other constituents than carbon, hydrogen, and oxygen, with the occasional addition of azote.

“Now Nature has accomplished this in a manner not less simple than unexpected, namely, by forming out of the three or four simple bodies above enumerated, an assemblage of proximate principles, possessing the properties and relations that belong to the elements existing in the mineral kingdom. Thus organic chemistry may be said to possess its own peculiar constituents, some of which stand in the same place and relation to others, as oxygen, chlorine, &c., and others in that of the metals and simple combustibles, so that the fundamental distinction between inorganic and organic chemistry is, that in the former the radicals are, so far as is known, simple, in the latter they are compound.

“Perhaps, indeed, this distinction may be only apparent, and it will eventually turn out, that the radicals found in mineral substances are themselves compound, although they have hitherto resisted decomposition.”

Waving the consideration of the bold speculation thrown out in the concluding sentence, which indeed will be alluded to elsewhere, I shall content myself with illustrating briefly the ordinary constitution of organic bodies, by reference to a few classes of compounds, in which the above principle of combination appears to be best established.

The radicals of organic acids at present recognised are certain compounds of carbon, such as cyanogen, mellon, benzoyle, cinnamyle, salicine, &c., to which we must now add two new ones traced out by Mr. Brodie in his researches on wax, namely, paraffin and melen.

Of these, cyanogen, mellon, and paraffine are already ascertained, the others being assumed to exist on analogical reasoning alone.

The radicals of bases are cacodyle, methyle, ethyle, glyceryle, amyle, cetyle, and perhaps a few more, but kakodyle is the only one actually ascertained, unless the late researches of Mr. Frankland warrant us in concluding the same with respect to ethyle, methyle, and amyle.

Referring to general works on organic chemistry for a full detail of the combinations to which each of these radicals gives rise, I will endeavour briefly to illustrate the method by

which their composition is determined, first by noting down the compounds derived from one of those in the first series which has been actually isolated, and then by comparing with them an analogous series of connected bodies derivable from one of the others, whose existence is assumed merely, but not demonstrated.

It is to Gay-Lussac that we are indebted for the discovery of the first of these, namely, cyanogen, and thereby for the recognition of the great principle, that a body need not be one of those regarded as simple, in order to form the basis of a number of combinations, and to hold the same relation to the other constituents of a compound, which elementary substances are supposed to do amongst minerals.

Cyanogen then is a compound radical made up of C2 N1, and represented by the symbol Cy.

Now

- Cy 1 + oxygen 1 forms cyanic acid.
- 1 + — 1 + Aq. 1 hydrated cyanic acid.
- 2 + — 2 + — 1 fulminic acid.
- 3 + — 3 + — 1 cyanuric acid.
- 3 + — 3 + — 3 hydrated cyanuric acid.
- 1 + hydrog. 1 ——— hydrocyanic or prussic acid.
- 1 + iron 1 ——— ferrocyanogen.
- 1 + sulphur 1 ——— sulphocyanic acid.

There are many other combinations of this

radical, but the above may suffice for the purpose of shewing, that it acts as oxygen, chlorine, iodine, or other simple bodies, possessing the same electrical condition, would do, with reference to substances in an opposite state to themselves.

Let us next take another series of organic combinations, in which the existence of a compound radical is supposed, but not demonstrated.

The radical of the benzoic acid, called benzoyle, is regarded as a compound of $C_{14} H_5 O_2$, and is denoted by the symbol Bzo.

Now

Bzo + 1 oxygen	forms benzoic acid.
Bzo + 1 + 1 Aq.	— hydrated benzoic acid.
Bzo + 1 hydrogen	— hydruret of benzoyle.
Bzo + 1 chlorine	— chloride of do.
Bzo + 1 iodine	— iodide.
Bzo + 1 sulphur	— sulphuret.
Bzo + 1 cyanogen	— cyanide.

In the former part of this chapter, I have brought together many examples of the substitution of one element for another, without any remarkable change of properties supervening, but here we have an instance of the reverse, for by the substitution of hydrogen for oxygen we obtain, instead of that mild inactive acid, the benzoic, which exists in gum benzoin, and is used as a perfume, the highly poisonous principle, hydruret

of benzoyle, which is found in the essential oil of bitter almonds.

But, with the exception of a few cases in the naphthaline series pointed out by Laurent, which at present stand in a manner isolated*, we have as yet no instance of the substitution of oxygen, as we have of chlorine, for hydrogen, without an entire change ensuing, and the removal of the compound into a different class of bodies—namely, into that of acids, the type apparently being broken up, and the properties in consequence reversed.

It must therefore not be concluded, that the qualities of a body depend wholly upon the arrangement and number of its particles, but accepting the facts before us, without any attempt in the present state of our knowledge to reconcile or to account for them, we cannot help inferring, that both the nature of the combining

* Laurent states, that when ninaphthase ($C_{20}H_7NO_4$) is acted on by hydrate of lime, a new body is formed, consisting of $C_{20}H_7O$, in which therefore O would seem to have taken the place of NO_4 . Also, that when nitric acid acts upon chloride of chlonaphthose. ($C_{20}H_4Cl_4 + Cl_2$), a compound is formed, consisting of $C_{20}H_4Cl_2O_2 + O_2$, in which O_2 not only replaces Cl_2 in the chloride, but also enters into the composition of the base itself, as may be seen by comparing the two formulas above given.

elements, and the manner in which they are grouped together, may concur in determining the character of the resulting compound.

Let us next select from the second series a radical, which bears the same relation to the metals, which cyanogen does to oxygen and chlorine.

There is a peculiar liquid distinguished by its highly offensive odour, which Cadet its discoverer obtained, by distilling dry acetate of potass along with its own weight of arsenious acid.

This substance, Bunsen, the distinguished chemist of Marburg, found to consist of 1 atom of arsenious acid, combined with 1 of oxygen, 4 of carbon, and 6 of hydrogen; and in the course of his inquiries he also hit upon another liquid, possessing a penetrating odour of garlic, and bursting into flame on coming into contact with the atmosphere, which differed from the former only in containing no oxygen, as it consisted of arsenious acid 1, carbon 4, hydrogen 6.

Now by regarding the latter as a compound radical, and the former as its oxide, he was enabled to deduce the composition of an entire series of allied bodies, which presented themselves to him whilst investigating this subject, in conformity with the general laws of atomic combination.

The body then which Bunsen regards as the radical, and which from its offensive odour he denominates kakodyle, consists of $C_4H_6 + As$ (As being the symbol of arsenious acid), and is denoted by Kd.

Now

Kd+O forms oxide of kakodyle, Cadet's fuming liquor also called alkarsine.

Kd+O₃ forms kakodylic acid, or algargen.

Kd+S — sulphuret of kakodyle.

Kd+Cl — chloride.

Kd+Br — bromide.

Kd+I — iodide.

Kd+F — fluoride.

Kd+Cy — cyanide.

Here then we have a compound radical, which acts exactly as a metal, and which when alone or united with 1 atom of oxygen, is highly offensive, poisonous, and inflammable, but when saturated with oxygen is inodorous, harmless, and inactive.

Now let us select a compound radical whose existence was assumed on hypothetical grounds, and trace the analogy between the compounds related to it; and those derivable from either of the two above noticed.

If we suppose then a body to exist, consisting of C_4H_5 , the relation borne by it to ether,

alcohol, and other organic compounds will be so simple, that it may be set down as its radical, and hence it has been proposed to designate it by the term ethyle, and to assign to it the symbol *Ae*.

Ae then with 1 of oxygen represents the composition of sulphuric ether, viz. $C_4 H_5 O$, which with 1 atom of water constitutes alcohol ($C_4 H_5 O + Aq.$), and the substitution of sulphur for oxygen, and of sulphuretted hydrogen for water, converts alcohol into mercaptan, a curious liquid consisting of $C_4 H_5 S + HS$.

As for the other sorts of ether, they appear to be made up, either of the radical ethyle, or of its oxide, sulphuric ether, combined with various elements.

Thus muriatic ether is *Ae Cl*, chlorine being substituted for oxygen; nitric ether is *Ae O + NO 3*, hyponitrous acid being substituted for the water present in alcohol; sulphovinic acid, a compound of sulphuric acid ($S O_3$) 2 atoms, ether ($C_4 H_5 O$) 1 atom.

Lastly, acetic acid, or pure vinegar, when deprived as much as possible of water, consists of $C_4 H_3 O_3 + Aq.$ Now on comparing this with alcohol, it will be seen, that the only difference is, that the acid contains 2 atoms less of hydrogen,

and 2 more of oxygen, so that it would seem that the change of vinous spirit into vinegar is effected by the substitution of 2 atoms of oxygen for 2 of hydrogen. But although this be a correct expression of the ultimate change brought about, yet it would appear, that an intermediate substance already alluded to under the name of aldehyde, is formed in the first instance from the alcohol, by the removal of 2 atoms of its hydrogen, the composition of aldehyde being $C_4H_3O + Aq$, and that the latter is converted into hydrated acetic acid by the addition of O_2 . According to either view the relation of alcohol to acetic acid is sufficiently obvious.

Now, it will be convenient, before we proceed further, to explain, that the term *alcohol* is employed, not only as designating the intoxicating liquid produced by the process of saccharine fermentation, but likewise as a generic term for a class of bodies, belonging to the same type, or framed upon the same principle. Just as the term *salt*, originally applied to chloride of sodium, or the condiment with which we season our food, is now extended to a class of bodies often destitute of savor; as the term *metal* designates several

substances which do not possess, either the malleability, the specific gravity, or the power of resisting heat, which distinguished those from which the word was borrowed; and as that of *acid* appertains to many having neither a sour taste nor any caustic properties, so that of *alcohol* indicates a class, some members of which, far from being volatile, are not even liquid, and instead of kindling readily, require a pretty high temperature for ignition.

The following are the properties by which the genus alcohol may be distinguished.

When subjected to the action of oxydizing bodies, it loses 2 atoms of hydrogen, which are sometimes replaced by 2 equivalents of oxygen, when it is converted into an acid, and in other cases parts with the same, without acquiring oxygen in its room, when it produces an aldehyde.

Under the influence of bodies possessing a strong affinity for water, such as sulphuric acid, chloride of zinc, anhydrous phosphoric acid, &c., it has a strong tendency to lose 2 atoms of water, and to be transformed into carburetted hydrogen, or else to split into water and ether.

When exposed to the action of chlorine, al-

dehydes are formed from it owing to the removal of 2 of its atoms of hydrogen.

In the case of the alcohol produced from vinous fermentation, which may be distinguished by the name of wine alcohol, we find a body consisting, according to Liebig, of the oxide of an hydrocarbon having the proportion of C4 to H5, and united to an atom of water.

This may be converted into acetic acid by the abstraction of H2, and the addition of O2, through the agency of potass *, and in other ways.

Other hydrocarbons, known or supposed to exist, form similar combinations with oxygen and

* Dumas (Mémoires Chimiques) explains this, by the affinity of hydrate of potass for carbonic acid, inducing in the first instance the resolution of the alcohol into that compound, this taking place through the decomposition of the water present in the hydrate, the hydrogen of which is disengaged, whilst its oxygen carries off the hydrogen of the alcohol.

Thus alcohol	C4 H6 O2
is broken into	C2 H2 O2
	<hr/>
and	C2 O4

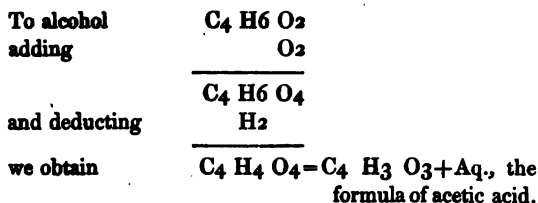
in the former of which cases, the atoms of hydrogen being replaced by their equivalents of oxygen, we obtain, as in the latter, C2 O4, or 2 atoms of carbonic acid.

This however is only the first step in the process of transformation, for acetic acid is afterwards formed from the re-

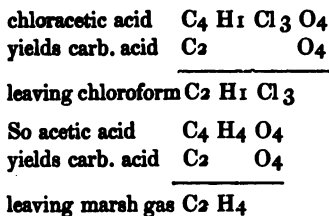
224 *Other compound radicals convertible*

water, each of which, according to the view taken by Liebig, would be regarded as the hydrated oxide of the particular compound radical, and hence they in like manner are called by analogy the alcohols of the bases to which they are allied, since they possess the properties mentioned above as characteristic of the class.

mainder of the alcohol, owing to the mere addition of O_2 in the place of H_2 , thus



Now we can understand the formation of marsh gas and of carbonic acid from acetic acid, on the same principle that chloroform and carbonic acid are obtained from chloracetic acid under the influence of potass, for as

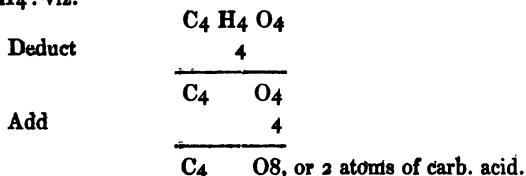


and likewise how it may happen, that acetic acid is resolved

Each of these alcohols may be converted into an acid by the substitution of 2 atoms of oxygen for 2 of hydrogen, but the contrary process has never yet been effected, for we know of no method of converting acetic acid into wine-alcohol by replacing 2 atoms of oxygen by 2 of hydrogen, and the same remark applies to the alcohols related to other hydrocarbons.

As art can *unite* carbon with oxygen, but has no ready means of effecting the disjunction of the two when united, which nature is constantly doing, so it can replace hydrogen by oxygen in

into carbonic acid alone, namely, by the substitution of O₄ for H₄: viz.



Thus may be explained the various products resulting from the action of hydrate of potass upon alcohol—namely, the evolution of hydrogen, the production of carbonic acid which unites with the potass, the formation of acetic acid from the same, and the resolution of the latter into marsh gas and carbonic acid.

A similar process takes place in the common experiment of producing phosphuretted hydrogen, by digesting phosphorus with potass and water.

the alcohols, but is as yet incapable of achieving the converse process, by replacing the oxygen of the acids by an equivalent amount of hydrogen.

I must next point out three analogous series of bodies, each of which is considered to have as its radical or base a compound of carbon and hydrogen, and to be similarly related one to the other.

The first of these is the supposed radical of wood spirit, otherwise called pyroxylic spirit, an inflammable liquid distilled from wood, which bears a near resemblance to alcohol.

Now Liebig derived this in a similar manner from a then hypothetical principle, composed of $C_2 H_3$, which he called methyle, and designated by the symbol Me.

Although this principle had not at the time been isolated, yet by distilling together sulphuric acid and pyroxylic spirit he obtained a kind of ether, called methylic ether, consisting of $C_2 H_3 O$, or $Me + O$, and to this pyroxylic spirit bears exactly the same relation, which alcohol does to sulphuric ether, its composition being $C_2 H_3 O + Aq$.

Similar combinations exist between the acids and methylic ether, as between the same bodies

and the oxide of ethyle; thus we have a compound called sulphate of methyle, consisting of $\text{Me O} + \text{S O}_3$, and the acid of ants, the hydrated formic acid, which may now be produced artificially by the oxidation of pyroxylic spirit, bears the same relation to this liquid, which acetic acid does to alcohol, consisting of $\text{C}_2 \text{HO}_3 + \text{Aq}$, or pyroxylic spirit, having 2 atoms of oxygen substituted for 2 of hydrogen.

Let us next proceed to another compound radical, assumed to be the base of that oil, which is present in all the inferior kinds of spirit, and communicates to them its peculiar taste and smell.

Being abundantly obtained during the distillation of potatoes, the source of the cheaper sorts of brandy consumed in Germany, the name of oil of potato spirit, or fusel oil, has been assigned to it, and its composition appears to be, $\text{C}_{10} \text{H}_{12} \text{O}_2$, or $\text{C}_{10} \text{H}_{11} \text{O} + \text{Aq}$.

Now if we regard this as the alcohol of the supposed radical, we may set down the latter as composed of $\text{C}_{10} \text{H}_{11}$, assigning to it the name of Amyle, and the symbol Ayl , and suppose it to form with oxygen an ether, which latter with 1 atom of water constitutes the oil in question.

Proceeding upon this hypothesis, we shall be

able to deduce the composition of various compounds formed from the oil of potato spirit, in accordance with the formulæ laid down with reference to the ethyle and methyle series.

Thus we have the bromide and the iodide of the supposed radical, composed of $\text{Ayl} + \text{Br}_2$, and $\text{Ayl} + \text{I}$; we have a compound of sulphuric acid with oil of potato spirit, $\text{Ayl O} + \text{Aq} + \text{S O}_3$, &c.; and, what is more remarkable, we have, in the valerianic acid which exists in the vegetable kingdom amongst the valerian tribe, but which may be also obtained artificially by heating the oil of potato spirit with fused potass, an analogue to the acetic and formic acids, 2 atoms of oxygen being substituted for 2 of hydrogen, oil of potato spirit, $\text{C}_{10} \text{H}_{11} \text{O} + \text{Aq}$, becoming valerianic acid, $\text{C}_{10} \text{H}_9 \text{O}_3 + \text{Aq}$.

There is one other analogous class of combinations which deserves to be briefly pointed out, in order to render more complete this account of the hydrocarbons known to give birth to alcohols and ethers.

If spermaceti be fused with hydrate of potass two products are obtained, namely, a white crystalline mass fusible below 118° , called ethal, the composition of which is $\text{C}_{32} \text{H}_{34} \text{O}_2$, and an acid

fat, called cetylic or ethalic acid, composed of $C_{32}H_{32}O_4$.

Now if we assume the existence of an hydrocarbon consisting of $C_{32}H_{33}$, and further that of an oxide of this compound radical, analogous to ether, having the formula $C_{32}H_{33}O$, ethal will be the alcohol of such a compound, being represented by the addition of HO to the ingredients, and cetylic acid the analogue to acetic acid, formed by the substitution of 2 of oxygen for 2 of hydrogen. Spermaceti is a compound of cetylic acid with the oxide of cetyle, or the ether of this radical, but the latter cannot be obtained separately.

In concluding this chapter, I will present my readers with a tabular view of the compounds deduced from the four radicals last alluded to.

I. <i>Methyle series.</i>	II. <i>Ethyle series.</i>	III. <i>Amyle series.</i>	IV. <i>Cetyls series.</i>
<p>$C_2 H_3$ symbol Me. Me + O — Methylic Ether</p>	<p>$C_4 H_5$ symbol Ae. Ae + O — Sulphuric Ether</p>	<p>Cro H_{11} symbol Ayl. Ayl + O — Not discovered</p>	<p>Cetyls $C_{32} H_{33}$ symbol Ct. Ct + O = Oxide of Cetyls, only found in combination</p>
<p>Me + O + Aq. — Pyroxylic spirit, or Wood Alcohol</p>	<p>Ae + O + Aq. — Wine alcohol</p>	<p>Ayl + O + Aq. Fusel oil, the Alcohol</p>	<p>Ct + O + Aq. — Ethal, the Alcohol</p>
<p>Me + O + Acid. — Compound Esters, viz.</p>	<p>Ae + O + Acid — Compound Esters, viz.</p>	<p>Ayl + O + Aq. — Sulphate of Amyls</p>	<p>Ct + O + Acid — Compound Esters, viz.</p>
<p>Me + O + SO_3 — Sulphate of Methyle</p>	<p>Ae + O + $2(SO_3) + Aq.$ — Sulphovinic acid</p>		<p>Ct + O + $2(SO_3) =$ Bisulphate of oxide of Cetyls, only found in combination.</p>
<p>Me + O + $C_2 HO_3$ — Formic Ether</p>	<p>Ae + O + NO_3 — Nitrous ether</p>	<p>Ayl + Br. — Bromide of Amyls</p>	<p>Ct + Cl — Chloride of Cetyls</p>
<p>Me + Cl — Chloride of Methyle</p>	<p>Ae + Cl — Muric ether</p>	<p>Cro $H_{11} O + Aq.$ Fusel oil</p>	<p>$C_{32} H_{33} O + Aq.$ — Ethal</p>
<p>$C_2 H_3 O + Aq.$, or Pyroxylic spirit</p>	<p>$C_4 H_5 O + Aq.$ or Wine Alcohol</p>	<p>losing H_2 Cro $H_9 O + Aq.$ gaining O_2 becomes Cro $H_9 O_3 + Aq.$ = Valerianic acid</p>	<p>losing H_2 $C_{32} H_{31} O + Aq.$ gaining O_2 $C_{32} H_{31} O_3 + Aq.$ = Ethalic or Cetylic acid</p>
<p>$C_2 H_1 O_3 + Aq.$ — Formic acid</p>	<p>$C_4 Cl_3 O_3 + Aq.$ — Chloroacetic acid</p>		
<p>$C_2 H_1 Cl_3$ — Chloroform</p>			

CHAPTER VIII.

Same subject continued—Application of the law of substitution to the explanation of the formation of the vegetable alkalies—acids—aldehydes—and alcohols—Dumas' view of the composition of these bodies—Brodie's discoveries with respect to the principles contained in wax, and their relation to the bodies before described—Isomeric bodies therefore owe their difference of properties—sometimes to a different arrangement of their particles—sometimes to a difference of crystallization, as in the tartaric and paratartaric acids—sometimes to a difference in aggregation—Attempt to explain the manner in which the properties of the compound may be affected by these causes—Difference between isomeric and dimorphous bodies.

IN the last chapter I traced the relation subsisting between that multifarious class of combinations, belonging to, or at least proceeding from, one or other of the two kingdoms of organized nature, which recent investigations have brought to light, and pointed out three distinct series of bodies, the members of each of which are formed

upon the same model, namely, the alcohols, the acids, and the aldehydes.

Thus, as we have seen, wine-alcohol may be supposed to be produced, by the addition of an atom of water to the oxide of the radical ethyle, aldehyde by the abstraction of 2 atoms of hydrogen from the same oxide, and acetic acid by the addition of 2 atoms of oxygen to aldehyde; or if we prefer so to represent it, by the substitution of 2 atoms of oxygen for 2 of the atoms of hydrogen present in the alcohol.

Precisely in this same manner, it is found, that an alcohol and an acid exist, related to the radicals methyle, amyle, and cetylc, the composition of both which may be explained on a similar principle.

But there is another class of organic compounds not hitherto adverted to, the members of which also exhibit as great an harmony in their composition and in their relations to each other, as those we have been considering—a class too in itself of considerable interest, inasmuch as most of the important medicines, as well as of the formidable poisons derivable from the vegetable kingdom, appear to owe their efficacy to bodies belonging to this series.

The class I allude to is that of the vegetable alkalies, the first of which was revealed to us so early as the beginning of this century, in the discovery made by Sertürner of the principle called morphia, derived from opium, since which time the list has become very numerous, embracing among the rest cinchonine and quinine, obtained from Peruvian Bark, the most valuable perhaps of our medicines, and strychnine, from the *Nux Vomica*, one of the most active of known poisons.

It had long been ascertained, that nitrogen was an essential ingredient of all the members of this class, and hence it was suspected, that they bore some relation to the volatile alkali, or to ammonia.

But what this exact relation might be, was a point upon which chemists were much divided.

By Berzelius it had been conceived, that they were formed, by the union of the ammonia pre-existing in the vegetable, with various combinations of carbon and hydrogen; by Liebig, that they arose out of the chemical action which took place between ammonia and an organic oxide, chloride, &c., resulting in the separation of 1 atom of hydrogen from the former, and of 1 atom of oxygen from the latter, together

with the union of the residues of both, so as to form the alkali in question.

This latter theory was favoured by the analogous fact, discovered by Dumas, that namely, of the production of a class of compounds called *amides*, from ammonia and an acid, in which 1 atom of hydrogen was in like manner abstracted from the former, and 1 of oxygen from the latter, the remaining atoms combining. Thus, oxamide, $C_2 O_2 H_2 N$, the type of this class, is produced by heat from oxalate of ammonia, which consists of $C_2 O_3 + H_3 N$; O being eliminated from the acid, and H from the alkali, whilst the remaining elements combining together form a compound, constituted as is above stated.

Now a brilliant discovery was announced in the course of last year by a German chemist, M. Wurtz, which went to prove, that organic alkalies might actually be created, by decomposing with potass the cyanates of ethyle, of methyle, and of amyle, which were thus split up into carbonic acid, and an alkali consisting of the radical united to ammonia, *minus* 1 atom of hydrogen, which latter had been eliminated along with the oxygen of the ether*.

That this would happen, had been predicted by

* The following, for example, are the changes that take

the sagacity of Liebig in 1840, but the fulfilment of his anticipation in the course of last year was reserved for Wurtz.

The alkali derived from cyanate of ethyle he calls ethylamide, that from cyanate of methyle methylamide; they are both volatile like ammonia, both possess the same pungent smell, although somewhat modified by the presence of another body, and both form compounds with chlorine which are analogous to sal-ammoniac.

The composition of

Methylamide is $C_2 H_5 N = C_2 H_3 + H_2 N$

Ethylamide $C_4 H_7 N = C_4 H_5 + H_2 N$

Amylamide $C_{10} H_{13} N = C_{10} H_{11} + H_2 N$

In these instances then, we may suppose a compound of $H_2 N$ to have united with the radical in question, forming the alkali, or in other words the substance to be produced by the substitution of the hydrocarbon for 1 of the atoms of hydrogen which constituted ammonia.

place in the case of cyanate of oxide of ethyle when decomposed by potass :

Cyanic acid 1 atom $C_2 NO$

Oxide of ethyle — $C_4 H_5 O$

Hydrate of potass. . 2 atoms $K_2 O_2 + H_2 O_2$

after mixture

Carbonate of potass 2 atoms $C_2 O_4 K_2 O_2$

New alkali. 1 atom $C_4 H_7 N$

or Ethyle $C_4 H_5 + H_2 N$

But Dr. Hoffmann, in a late important paper published in the Phil. Transactions for 1850, has still further generalized upon these conclusions, and has shewn, that not only one, but all the three atoms of hydrogen present in ammonia, may be replaced by various hydrocarbons, forming a long series of organic alkalies, some of which, artificially produced, are isomeric with others existing in nature, although in their properties somewhat distinguished from them.

In order to comprehend the nature of his proofs, it will be necessary to premise, that the hydrocarbons, capable of thus associating themselves with the elements of ammonia, and of replacing its hydrogen, are probably very numerous, and Hoffman has at least shewn, that they are not limited to the three, which Wurtz had proved to enter into the composition of his new alkalies, namely, to ethyle, methyle, and amyle.

Another hydrocarbon, which frequently takes a part in these combinations, is a body not hitherto noticed, but supposed to be the basis of those interesting compounds, which have been obtained, through the researches of Crum, Laurent, Dumas, Berzelius, and Dr. Hoffmann himself, from the indigo of commerce.

Indigo is extracted from a variety of plants, in which it exists in a colourless form, constituting what is called white indigo, which becomes blue on exposure to light and air.

The difference between the two sorts appears to consist, in the presence of 1 atom more of hydrogen in blue indigo than in white, the first consisting of $C_{16} H_5 N O_2$, the latter of $C_{16} H_6 N O_2$.

Now when indigo is oxidized by means of nitric acid, it becomes converted into a bright red crystalline body termed isatine, which appears to consist of $C_{16} H_5 N O_4$, or to be white indigo + O_2 .

This substance, if heated along with potass, yields an organic base capable of neutralizing acids, and in many respects analogous to ammonia, which is called aniline.

The latter may be obtained, not only from indigo and its combinations, but likewise, as Hoffmann has proved, from coal tar, and from nitrobenzide, one of the combinations of benzoic acid, and is indeed remarkable for the variety of sources from whence it is derivable.

Now aniline is regarded by Hoffmann as a combination of nitrogen 1, hydrogen 2*, with

* Compounds of $N H_2$ have been hitherto called amides, being produced from ammonia ($N H_3$), through the ab-

a compound radical called *phenyle*, a name given by Laurent to the supposed base of the volatile liquid, obtained by compressing oil gas, which was first examined by Faraday, and denominated by him benzole.

According to Laurent, this latter is an hydruret of his supposed radical *phenyle*, its composition being $C_{12} H_6$, or phenyle ($C_{12} H_5$) + H^* .

Aniline, therefore, may be regarded as an alkali, in which 1 atom of the hydrogen present straction of 1 atom of hydrogen, but this name will probably be now discarded, owing to the new views which the above discoveries have introduced into chemistry.

* The following exhibits Laurent's views of this series of compounds, with the exception of the last, for which I am indebted to Hoffmann :

Phenyle	$C_{12} H_5$
Benzole	$C_{12} H_5 + H$
Hydrated oxide of phenyle	$C_{12} H_5 + O + Aq.$
Sulphophenic acid	$C_{12} H_5 + O + Aq. + 2SO_3$
Chlorophenesic acid	$C_{12} \left\{ \begin{smallmatrix} H_3 \\ Cl_2 \end{smallmatrix} \right\} + O + Aq.$
Chlorophenisic acid.....	$C_{12} \left\{ \begin{smallmatrix} H_2 \\ Cl_3 \end{smallmatrix} \right\} + O + Aq.$
Chlorophenusic acid	$C_{12} Cl_5 + O + Aq.$
Bromophenisic acid	$C_{12} \left\{ \begin{smallmatrix} H_2 \\ Br_3 \end{smallmatrix} \right\} + O + Aq.$
Nitrophenesic acid	$C_{12} \left\{ \begin{smallmatrix} H_2 \\ 3N O_4 \end{smallmatrix} \right\} + O + Aq.$
Aniline.....	$C_{12} H_5 + H_2 N.$

in ammonia is replaced by an atom of phenyle, thus : $C_{12} H_5 + H_2 N = C_{12} H_7 N$.

Hoffmann has shewn, that this same hypothetical base is one of those, which enters most frequently into the composition of bodies possessing the properties of organic alkalies, and he conceives, that in many instances more radicals than one are present at the same time, for if ethyle replaces the first of the atoms of hydrogen present in ammonia, phenyle may replace the second atom, and methyle the third, thus rendering possible the formation of as many distinct alkalies, as might be produced, by ringing the changes on all the various hydrocarbons, capable of being substituted for the atoms of hydrogen in ammonia.

Thus, as instances of alkalies formed by the replacement of a single atom of hydrogen by the bodies supposed, we have

Aniline . . . , $C_{12} H_5 + H_2 N$, where 1 atom of hydrogen is replaced by phenyle.

Methylamine $C_2 H_3 + \text{---}$, where it is replaced by methyle.

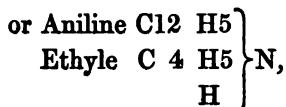
Ethylamine. . $C_4 H_5 + \text{---}$, where it is replaced by ethyle.

Amylamine. . $C_{10} H_{11} + \text{---}$, where it is replaced by amyle.

As instances of the same produced by the

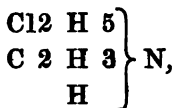
replacement of 2 atoms, Hoffmann has presented us with the following:

1 Ethylaniline where 1 atom is replaced by aniline,
and 1 ————— ethyle,
its composition being C16 H11 N



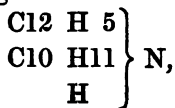
is a transparent oil, much resembling in its properties aniline, and capable of forming similar salts.

2 Methylaniline, where the second atom is replaced by methyle instead of ethyle, its composition being such as admits of being represented as follows:



is, like the former, very analogous in its sensible properties and chemical relations to aniline.

3 Amylaniline, a similar compound, into which amyle, as well as aniline, appears to enter, its composition being



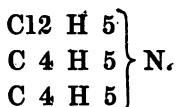
by replacement of 2 & 3 atoms of hydrogen. 241

and its properties presenting the family features of the group.

4 Diethylamine, in which 2 atoms of hydrogen are replaced by 2 of ethyle.

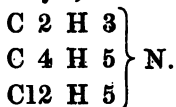
As instances of Alkalies produced by the replacement of all the three atoms of hydrogen by hydrocarbons, Hoffmann gives us the following :

1 Diethylaniline, in which 1 atom of aniline and 2 of ethyle usurp the place of hydrogen, its formula being

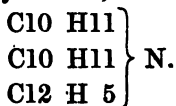


Its properties resemble those of ethylaniline, but it has an higher specific gravity, and rather less volatility.

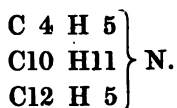
2 Methyl ethylaniline, where one atom is replaced by methyle, 1 by ethyle, and 1 by aniline, thus :



3 Diamylaniline, where 2 atoms are replaced by amyle and 1 by aniline, thus :



4 Ethylamylaniline, 1 of ethyle, 1 of amyle, and 1 of aniline, its formula being



5 Triethylamine*, consisting of 3 atoms of ethyle replacing 3 of hydrogen, thus :



Such are the new substances obtained by Dr. Hoffmann in the prosecution of his valuable researches on the volatile organic bases, but the most remarkable part still remains to be told, namely, that three of the artificial products discovered exactly correspond in composition, although not

* As Würtz has chosen to assign to the alkalies of his discovery the names of methylamide, ethylamide, and amylamide (see p. 235), it might be thought advisable, for the sake of uniformity, to write triethylamide, ethylamylanide, &c. instead of the names given in the text.

But the termination *ide* is already set apart for the compounds of radicals with chlorine, oxygen, &c., so that it will be better to adapt Würtz' names to those given by Hoffmann, changing the former into methylamine, ethylamine, and amylamine.

in properties, with three vegetable alkalies already known to us, methylaniline being identical with toluidine, an alkali obtained from the balsam of Tolu; ethylaniline with xylidine, obtained from the distillation of wood; and methylethylaniline with a substance called cumidine, lately discovered by Mr. Nicholson in the oil of caraways*.

It becomes therefore highly probable, that the other vegetable alkalies will turn out compounds, in which various hydrocarbons have replaced one or more of the hydrogen atoms of ammonia, or in which nitrous acid has acted the same part.

Such may be the case with those, like strychnine, quinine, &c. into which oxygen enters, and here also we see produced artificially an analogous body, for Hoffmann has discovered an alkali called nitraniline, in which nitrous acid, NO_4 , has taken the place of one of the atoms of phenyle, forming a compound of $\text{C}_{12} \text{H}_4 \text{NO}_4$; in lieu of $\text{C}_{12} \text{H}_5$; which replaces one of the hydrogen atoms of ammonia, and thus produces a body belonging to the same type as aniline itself, aniline being, as we have seen, $\text{C}_{12} \text{H}_5 + \text{H}_2 \text{N}$, nitraniline $\text{C}_{12} \text{H}_4 \text{NO}_4 + \text{H}_2 \text{N}$.

* See the Chem. Soc. Quart. Journ. I.

The above researches also throw a new light on those numerous combinations recognised by chemists hitherto under the name of *amides*, having the composition of $H_2 N$, being derived from ammonia, but with one of its atoms of hydrogen removed.

Thus *oxamide* was regarded as a compound of a body called amidogen ($H_2 N$) with $C_2 H_2$; benzamide of the same with the radical of benzoic acid; urea, the characteristic principle in the urine of all mammiferous animals, as a compound of 2 atoms of amidogen ($H_2 N$) with 2 of carbonic oxide; but it is now more simple and more consistent with analogy, to regard these as compounds, in which one or more of the atoms of hydrogen in ammonia have been replaced by some one of the compound bases — such as carbonic oxide, carburetted hydrogen, or the benzoic radical.

The above results are also in full accordance with those researches in vegetable physiology which were instituted several years ago by the French chemist M. Payen*, and which lead to the conclusion, that the spongioles of the roots always

* Mémoires sur le développement des Végétaux, 1844.

contain an azotized material, which is from them transmitted to all the other parts of the plant, appearing essential, not only to their growth, but even to their very existence—which shew likewise, that all the young organs, whether of the leaves, the flowers, or the fruit, contain this same azotized compound, in a quantity proportionate to the energy with which their development proceeds—and, moreover, establish the fact, that the assimilation of this material always takes precedence over that of the ligneous and cellular substance which forms the chief constituent of the vegetable fabric.

Hence, the absorption of a nitrogenized substance would seem to be, as it were, the starting point in the development of all living matter; or, as a German poet has long ago expressed it, four elements must combine in order to lay the foundation of an organic structure—

Vier Elemente
Innig gesellt
Bilden das Leben,
Bauen die Welt.

These elements being, not those vulgarly regarded as such—namely, earth, air, fire, and water—but oxygen, hydrogen, carbon, and ni-

trogen, together forming what is called a quaternary combination, of which most animal matters and some vegetable ones consist.

Probably, therefore, the first step in the formation of a fluid secretion, calculated to furnish the original germs of life to the plant, will be, the substitution of an hydrocarbon for one of the hydrogen atoms of the ammonia which the spongioles had imbibed, and the consequent fixation of the nitrogen therein contained*.

It is to be remarked, that almost all the more powerful alkalies betray the presence of oxygen, and may therefore be supposed to contain nitrous acid. As they are produced most abundantly in the warmer regions of the globe, where

* I cannot here refrain from reminding my readers of the speculations in which I have indulged, in my *Lectures on Agriculture*, 1841, and in my *Work on Volcanos*, 2nd edit. 1848, p. 694, relative to the efficient cause of the disengagement of ammonia from the interior of the earth through the operation of volcanos.

At any rate, whatever opinion we may entertain with respect to the original source of this gas, it must be admitted, that a provision has been made by nature for a regular and constant supply of it for the purposes of vegetation, in the presence of a certain amount of ammonia diffused throughout the atmosphere, and consequently brought down to the ground continually in rain, dew, snow, &c.

this compound is most freely generated, it is possible, that there may be some connexion between these two facts, and that the elaboration of the stronger vegetable alkaloids may be dependent on the presence of nitrous acid and its combinations.

And since phosphorus and arsenic are both isomorphous with nitrogen—as is shewn by the resemblances in crystalline form observed in some of their combinations, and in the similar proportions in which they unite with hydrogen and with oxygen—it may be suggested, that certain of the bodies, into whose constitution the two former elements are found to enter, may be derived, like the vegetable alkalies above mentioned, from the substitution of an hydro-carbon for one or more of the atoms of hydrogen previously associated with them.

Thus certain compounds lately discovered by Paul Thenard*, may, as Dr. Hoffmann suggests, be produced through the replacement, of 1 or more of the atoms of hydrogen present in phosphu-

* See Compt. rend. de l'Académie, vol. XXV.; or Phil. Mag., vol. XXXII.

retted hydrogen, by methyle or ethyle, one of those produced by the action of chloride of methyle upon phosphuret of calcium being a compound of $C_6 H_9 P$, in which we may suppose the 3 atoms of hydrogen replaced by 3 of methyle, as in triethylamine.

May not in like manner the compound radical, kakodyle ($C_6 H_6 As$), already mentioned, be formed in the same way, by the substitution of $C_6 H_4$, for one of the atoms of hydrogen existing in the analogous body called arsenuretted hydrogen, its real formula being



The discoveries of Dr. Hoffmann also relieve us from the burden of some of those hypothetical radicals, which have lately been so multiplied in organic chemistry.

Amidogen (H_2N) at least, introduced by Dumas, seems to have no real independent existence, but to be a name expressive only of ammonia, in which 1 of its hydrogen atoms is replaced by an equivalent of some hydrocarbon. Imidogen, by which name Laurent intended to express ammonia shorn of 2 of its hydrogen atoms, through the substitution of a similar base, will share the same fate, and it

may even be questioned, whether ethyle, methyle, and amyle, must not stand for the proportions of carbon and hydrogen which have a tendency to enter most readily into combination, rather than for actually existing organic bases.

I must not however omit to state, that a very able and elaborate series of experiments has been lately published by a promising disciple of the great school of Giessen, Dr. Frankland, from which it is inferred, that all these three supposed radicals have actually been isolated, bodies having been obtained, which possess precisely the composition of, $C_2 H_3$, $C_4 H_5$, and $C_{10} H_{11}$ *.

This is indeed rendered more probable by the previous discovery made by Dr. Kolbe, of a compound of carbon and hydrogen derived by electrolysis from the valerianic acid, and hence called valyle, the composition of which is such, as to supply one of the deficient links intervening between ethyle and amyle, as it holds the same relation to an acid called the butyric, which the two latter bodies do respectively to acetic and valerianic acids.

The question, however, as to whether these

* Quart. Journ. Ch. Soc. No. VII. and IX.

bodies can be laid down, as constituting the bases of the several combinations which have been deduced from the above three radicals, is still perhaps *sub judice*, since the difficulties, in the way of so regarding them, are considered by some not to have been wholly removed.

It seemed better for me, therefore, in an elementary treatise like the present, to avoid pronouncing any decided opinion on the subject, and to confine myself, as I have done, to a simple statement of those views and researches, which have already stood the test of time and of discussion.

I ought however to inform my readers, that a still simpler view of the constitution of the above compounds was long ago offered by Dumas, and adopted by the French school of chemists, by which the necessity for supposing the existence of such radicals, as methyle, ethyle, amyle, &c., would be altogether excluded.

By them it is conceived, that sulphuric ether is the compound of a radical containing the same elements as olefiant gas, viz. $C_4 H_4$, with 1 atom of water superadded, and alcohol a compound of the same radical, with 2 atoms.

In accordance with this hypothesis, pyroxylic spirit will be a compound of 2 atoms of water with $C_2 H_2$, or with the same elements as the former, in which 2 atoms of each, instead of 4, are united into one compound atom; fusel oil a compound of 2 atoms of water with a radical consisting of $C_{10} H_{10}$; and ethal of 2 atoms of water with $C_{32} H_{32}$.

This view of the subject would appear at first sight to deserve a preference, from the simple relation which it supposes between the carbon and hydrogen united, which will thus stand throughout the series as multiples, by the number 2, one of the other.

It may however be remarked, that the recommendation of superior simplicity applies only to the composition of the body which stands at the commencement of the series, for admitting a compound radical to exist, composed of $C_2 H_3$, it will be readily perceived, that all the remaining members may be built up by successive additions to it of equal multiples of carbon and hydrogen; for although several links in the chain are still undiscovered, still the bodies which may be assumed to have for their basis these radicals, stand with reference to each other in so regular an order of

sequence, as to lead to the inference that all of them may hereafter be found to exist.

It is at least remarkable, that there should be an extensive class of vegetable acids, whose constitution may be equally well explained, by supposing them built up by successive multiples of carbon and hydrogen, in the proportion of $C_2 H_2$, and acidified in all cases by exactly 4 atoms of oxygen, as by imagining them multiples of the same proportion of these elements laid on a nucleus of methyle, *acidified* by 3 atoms of oxygen, and *hydrated* by the addition to each of 1 atom of water.

It is important to observe, that the volatility of these acids diminishes in a direct ratio to the amount of carbon and hydrogen superadded to the original molecule, formic acid, the lowest member in the series, being highly volatile, ethalic, the highest, being a dense solid like wax.

In order that the two views of the composition of these and other allied bodies may be better understood, the following scheme of their composition according to each of these theories is presented in the annexed Table*.

* We may thus point out four classes of *homologous* bodies, to adopt the term which Gerhardt has proposed,

namely, alcohols, ethers, aldehydes, and acids, which might be severally represented, if we chose to adopt these views of the French chemists, as follows :

Alcohols 2 $\text{HO} + \text{C}_2 \text{H}_2$, or a multiple of the latter.

Ethers 1 $\text{HO} + \text{C}_2 \text{H}_2$, or ditto.

Aldehydes 2 $\text{O} + \text{C}_2 \text{H}_2$, or ditto.

Acids 4 $\text{O} + \text{C}_2 \text{H}_2$, or ditto.

To which, according to Würtz and Hoffmann, we have to add a fifth class, that namely of the alkalies, of which the formula would be $\text{N} + \text{R}_3$, in which R may be either simply hydrogen, or an hydro-carbon.

Table of the volatile oily acids, giving their constitution according to the respective views of Dumas and of Liebig, with their supposed Radicals on both these theories, and the Alcohols derived from them.

RADICALS.	ACIDS.	ALCOHOLS.
Methylene D. C_2H_2 Methyle . . . C_2H_3 losing C_2H_1	Formic acid . . $C_2H_2 + O_4$ ————— $C_2H_1 - O_3 + HO$	Wood spirit . . $C_2H_2 + 2HO$ ————— $C_2H_3 + O + HO$
Etherine D. C_4H_4 Ethyle C_4H_5 losing C_4H_2	Acetic $C_4H_4 + O_4$ ————— $C_4H_3 + O_3 + HO$	Wine spirit . . $C_4H_4 + 2HO$ ————— $C_4H_5 + O + HO$
Valyle C_8H_9 losing H_2	Metacetic . . . $C_6H_6 + O_4$ ————— $C_6H_5 + O_3 + HO$	
	Butyric $C_8H_8 + O_4$	
	Valerianic . . . $C_{10}H_{10} + O_4$	
Amyle $C_{10}H_{11}$ losing H_2	————— $C_{10}H_9 + O_3 + HO$	Fusel oil $C_{10}H_{10} + 2HO$ ————— $C_{10}H_9 + O + HO$

Supposed Alcohol
of Williamson.

Caproic $C_{12} H_{12} + O_4$
 $C_{12} H_{11} + O_3 + HO$
 Oenanthylic .. $C_{14} H_{14} + O_4$ }
 $C_{14} H_{13} + O_3 + HO$
 Caprylic $C_{16} H_{16} + O_4$
 $C_{16} H_{15} + O_3 + HO$
 Pelargonic.... $C_{18} H_{18} + O_4$
 $C_{18} H_{17} + O_3 + HO$
 Capric $C_{20} H_{20} + O_4$
 $C_{20} H_{19} + O_3 + HO$

*

Lauric $C_{24} H_{24} + O_4$
 $C_{23} H_{23} + O_3 + HO$
 Cocinic $C_{26} H_{26} + O_4$
 $C_{26} H_{25} + O_3 + HO$
 Myristic $C_{28} H_{28} + O_4$
 $C_{28} H_{27} + O_3 + HO$

*

Palmitic and } $C_{32} H_{32} + O_4$
 Ethalic acid } $C_{32} H_{31} + O_3 + HO$
 Margarin $C_{34} H_{34} + O_4$
 $C_{34} H_{33} + O_3 + HO$

Cetale D. .. $C_{34} H_{34}$
 Cetylo..... $C_{34} H_{35}$
 losing H_2
 $C_{34} H_{33}$

Ethal $C_{34} H_{34} + 2HO$
 $C_{34} H_{33} + O + HO$

With regard however to the respective merits of these two theories, I have no hesitation in giving the preference to that of Baron Liebig, who considers the lowest in the series of compound radicals to be constituted of $C_2 H_3$, and the remainder to be produced by the addition of equal quantities of the same two elements, although the grounds upon which I have been decided in favour of this view will be best stated in the Appendix.

Those however, like Gerhardt and Laurent, who still maintain the contrary notion, have a right to contend*, that the discovery of bodies possessing the composition ascribed to ethyle, methyle, and amyle, gives them no higher pretensions to be regarded as the radicals, than olefiant gas or light carburetted hydrogen can advance.

Both these latter bodies have long been ascertained to exist, and from one or other of these, the ethyle and methyle groups may, as we have seen, readily be deduced. Nor, it may be argued, can there be any ground for preferring the former,

* See Comptes Rendus de Chémie par Laurent et Gerhardt, 1849.

rather than the latter, as a starting point for the compounds which are derivable from them, until it can be shewn by direct experiment, that the latter may be obtained immediately from either one by the addition of certain other elements.

After all, Liebig's and Dumas' methods of representing the relation, subsisting between the several members of each series, will equally well serve the purpose, of displaying their mutual connexion, and of directing the line of our future inquiries, by pointing out what links are deficient in each.

Thus, it is probable, that an ether will be discovered, bearing the same relation to fusel oil, which sulphuric ether does to alcohol, and that a body analogous to aldehyde will be detected hereafter, as belonging to the methyle series.

Three excellent memoirs have lately been published by Mr. Brodie*, which serve to extend still further our knowledge of the hydrocarbons, and of their relations to alcohol, &c.

Mr. Brodie has shewn, that pure bees-wax is composed of two vegetable principles, the one of

* Phil. Trans. for 1849.

which is more soluble in boiling alcohol than the other, the substance most readily dissolved being called *cerin*, that less so, *myricin*.

Now the former of these he finds to possess the same composition, so far as relates to the carbon and hydrogen contained in it, as the solid matter discovered by Reichenbach in tar, and named by him paraffin, but to be charged in addition with 4 atoms of oxygen, paraffin being $C_{54} H_{54}$, cerin $C_{54} H_{54} + O_4$.

As cerin forms a soap with potass, Brodie regards it as an acid, which he therefore calls the cerotic.

He also detected in a species of wax from China a substance possessing the composition of $C_{54} H_{56} O_2$, which he calls cerotin.

Now, if we consider paraffin as the radical of these combinations, we may look upon cerin as its acid, formed by the addition to it of 4 atoms of oxygen, just as acetic acid may be deduced from olefiant gas ($C_4 H_4$) by adding the same amount; and cerotin may be viewed as its alcohol, formed by substituting 2 of hydrogen for 2 of oxygen, just as wine-spirit might be supposed to be derived from olefiant gas ($C_4 H_4$) by the addition of H_2 of hydrogen, and 2 of oxygen.

The ether of paraffin does not appear to have

been isolated, but a compound of it with sulphuric acid has been formed, the composition of which was $C_{54} H_{55} O + S O_3 + Aq.$, which might be otherwise represented as paraffin + Aq. (or ether) combined with $S O_3 + Aq.$

Hence the following would represent the relation between the several compounds noticed according to the views of Dumas :

Paraffin $C_{54} H_{54} + HO$ forms an *ether* met with combined with SO_3 .

————— + $H_2 O_2$ forms cerotin, the *alcohol*.

————— + O_4 forms cerin or *cerotic acid*.

The formula of these compounds expressed in conformity to Liebig's theory are sufficiently obvious.

In like manner the portion of bees-wax, not readily acted upon by alcohol, and called myricin, was found to contain a substance which Brodie distinguishes by the name of melissin, and which consists of $C_{60} H_{62} O_2$. He therefore regards this likewise as the alcohol of a body consisting of $C_{60} H_{60}$, which he obtained from the dry distillation of wax, and which he terms melin.

Melissin, like cerin, gives birth to an acid, which is called the melissic, consisting of $C_{60} H_{60} O_4$, so that an exact parallelism runs through this, and the former series.

The principle present in Chinese wax seems to be an acid like the cerotic, forming soap with alkalis, but in which 4 of oxygen are united to 2 atoms of paraffin, instead of 1.

Thus Mr. Brodie may boast of having enriched science with two new alcohols, an achievement, the importance of which will be estimated by chemists, when they recollect, that although the number of organic acids already known is so large, only four, or at most five, of their corresponding alcohols have been yet detected*.

Nor must I omit to point out, before concluding this subject, that the analogy between alcohol and wax is strengthened by finding, that the same saccharine matter, which during the process of fermentation gives rise to alcohol, in the body of the bee is converted into wax, and that the butyric acid mentioned above, which is obtained from fat, may be produced also by a species of fermentation from sugar.

The above account of the manner in which

* See the remarks of M. Dumas in his 2nd Memoir on Chemical Types, in the course of which he states, that to discover an alcohol, is to enrich organic chemistry with a series of products, analogous to those which the discovery of a new metal presents to us in mineral chemistry.—Hence the importance attached to an observation of this character.

organic compounds are built up from a number of radicals consisting severally of carbon and hydrogen, in the first place by the addition of certain elements, and afterwards by the substitution of others, seemed necessary for the purpose of duly understanding, how two or more distinct substances could be produced from the same elements, in the same proportions, put together according to a different plan.

We can now perceive, that assemblages of atoms, in all respects the same in number and in quality, may nevertheless belong to different types, and from their arrangement produce aggregates possessing few or no properties in common.

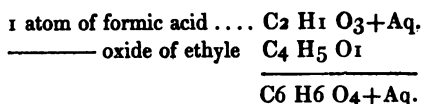
In some cases, this difference in the mode of grouping may arise from their being produced by distinct methods, as in the cases of formic ether, and acetate of methyle, two liquids containing exactly the same proportions of carbon, hydrogen, and oxygen, and agreeing in density in their gaseous as well as their liquid condition, yet in their properties shewing but little resemblance, and by the action of alkalies resolvable, the one into formic acid and alcohol, the other into acetic acid and pyroxylic spirit.

Formic ether, however, is produced by the

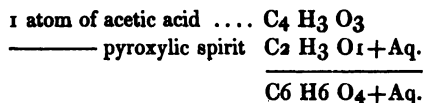
262 *Differences of properties arising from*

action of formic acid upon alcohol; acetate of methyle, by that of acetic acid upon pyroxylic spirit, the first belonging to the ethyle, the latter to the methyle series.

Hence in the former compounds the elements are arranged as follows :



and in the latter compound thus :



In other cases, this variation in the arrangement of the particles arises out of certain modifications in the processes to which they severally owe their origin, but which are of too subtle a nature to be appreciated.

Thus, for instance, the tartaric, and racemic or paratartaric acids, both alike originate in the secretions of the same species of plant, both possess the same atomic weight, and both produce analogous salts; yet they are distinguished by the more sparing solubility of the latter, by the greater force with which it retains its combined

water, and by other sufficiently marked peculiarities.

It is not easy, indeed, to conceive how these peculiarities arise, the tartaric being the acid more generally present in the juice of the grape; the racemic, chiefly found in that of vines cultivated in the district of the Vosges, and even there being dependent upon the condition of the seasons.

But although the efficient cause of the difference remains a mystery, its nature has been lately elucidated by the curious researches of Monsr. Pasteur of Paris*, which shew, that the chemical differences between the two acids are in some way dependent upon their structure or crystallization, although they fail to inform us, why this difference in the two cases should occur.

One point of distinction between the two acids consisted in the influence they exerted upon the direction of the rays of light, common tartaric acid being shewn by Biot to polarize the sunbeam to the right, whilst the racemic was endowed with no such effect.

Pasteur however discovered, that this inertness

* *Annales de Chémie*, vol. XXIV. p. 1848.

was owing to the coexistence in the latter case of the two acids in equal proportions, which, as they possessed in this respect opposite properties, consequently neutralized each other. When indeed the racemic acid was crystallized from a state of solution, all the crystals assumed the same form, and all were alike hemiedral*; but it was observed, that exactly half of them were hemiedral on the opposite side to the other half, so that one set bore the same resemblance to the other, which either set would do to its own image reflected in a mirror, or as the right hand does to the left.

Now, if we distinguish these two sorts of crystals by saying, that the one is hemiedral to the right, and the other to the left, it may be stated, that the former kind was found to consist of tartaric acid, and possessed of course the property of polarizing light as above stated, whilst the other, which was hemiedral in the reverse direction, polarized light to the left.

Thus, it would seem, that in the juice of the vines, grown in a particular district of France, there are produced two isomeric acids in exactly equal proportions, analogous indeed in many of their properties, but nevertheless contrasted in

* That is, half of their similar planes or angles were modified independently of the other half.

VIII. *Polymerism and metamerism explained.* 265

certain respects, as to their external forms, and exercising an influence upon light exactly the reverse of each other.

One of these acids is the tartaric, found alone in ordinary wines; the other still remains to be investigated. The racemic is a mixture of the two.

In conclusion then, it may be remarked, that the difference between bodies termed isomeric may be referred, to some variation either in the number of simple atoms which constitute in them a compound atom, or in that of the nature of the proximate elements from which the body is itself built up.

In the former case, the determining cause would seem to be *the degree* of aggregation; in the latter the *arrangement* of the particles with reference to each other.

The former case Berzelius has distinguished by the term *polymerism*; the latter, by that of *metamerism*.

Thus, olefiant gas and cetene are polymeric bodies; formic ether and acetate of methyle metameric.

Other instances of isomerism, not referable to either of these causes, seem to come under the

category of *allotropism*, which will be considered in another place.

For some of these cases, however, Dr. Prout supplied us with an ingenious and plausible explanation, assuming the presence in them of a minute portion of some foreign matter, which modified the properties of the staple ingredients in such a manner, as to impart new characters to the entire mass.

The change produced in the properties of iron by an infinitesimal portion of carbon, or in that of steel by a slight admixture of silver, platina, and other metals, and also the different relations to electricity imparted to mercury by being alloyed with less than a millionth part of potassium, are facts lending support to this hypothesis, which, moreover, is quite in accordance with the view above taken, as to the influence which the grouping of the particles exerts upon the nature of the aggregate, and may therefore be received as just, wherever the presence of this foreign matter has been demonstrated by experiment.

But if so great a change of chemical properties can be induced by a mere difference in the arrangement of the same particles, or even by their greater or lesser proximity one to the other, how

comes it, it may be asked, that we find the same body assuming two or more totally distinct forms, without undergoing any corresponding change in its nature—why for example do the particles of carbonate of lime, assume sometimes the form of calc-spar, sometimes of arragonite, without any change in its relations to other bodies?

Now the following suggests itself as a mode of accounting for this difference.

We may imagine every compound body to be made up of a congeries of integrant particles, every one of which must contain at least one atom, or if you please one group of atoms, of either constituent.

Thus every particle of carbonate of lime contains, at least one atom of carbonic acid, and one atom of lime.

Now it is easy to perceive, that a different arrangement of the integrant particles, unaccompanied by any change in the relative proportions of the atoms of which each of them is composed, may bring about a different description of crystal, so that in one instance we may have arragonite, in another calcareous spar, resulting from the same materials.

This then is what happens in a case of *dimorphism*; and it may be readily understood,

that such a variation in the arrangement of the integrant particles need not necessarily involve a change in the chemical properties of the mass.

Let us next assume, that the ultimate atoms, of which each of the constituents of this dimorphous body is composed, (as in the case before us, the ultimate atoms of carbonic acid and of lime,) undergo a change of arrangement. In this case we should have an *isomeric* body produced, an alteration having taken place in the chemical properties, no less than in the physical ones of density and crystallization.

The ancients, who were often happy in their mode of elucidating their ideas, compared the production of different bodies from the same elements, to the formation of different words by the transposition of the same letters. Thus Lucretius :

Jamne vides igitur, paullo quod diximus ante,
Permagni referre, eadem primordia sæpe
Cum quibus, et quali positura contineantur,
Et quos inter se dent motus, adcipiantque,
Atque eadem, paullo inter se mutata, creare
Igneis e lignis? quo pacto verba quoque ipsa
Inter se paullo mutatis sunt elementis,
Quum Ligna, atque Igneis distincta voce notemus.

Now to follow up this same analogy a little further, we may compare *isomeric* bodies to words

composed of the same letters differently arranged, and *dimorphous* ones to words consisting of the same syllables transposed, each syllable bearing the same relation to the word it contributes to form, which each integrant particle of a compound does to the substance produced by its union with others.

Just in the same manner, if we place two bodies of the same constitution near each other, neither one is affected in consequence, but if two dissimilar ones are brought into contact, negative electricity is excited in the one, and positive in the other, from which superinduced condition new properties are evolved in each.

But how are we to explain the second difficulty, namely, why the same body should sometimes affect one crystalline form, and sometimes another?

On this subject we are, it must be confessed, still much in the dark, but some little light has been thrown upon the question by the researches of Mitscherlich, who has shewn, that heat in many cases tends to modify the crystallization of a body, by causing it to expand unequally in different directions, enlarging the acute angles, and thus imparting to it a tendency towards the cube.

Hence it is very possible, that the same substance, if made to crystallize at a high temperature may assume a different form from that which belongs to it at a lower one; and this is actually found the case with carbonate of lime, which, when deposited from a solution in the cold, takes the rhomboidal form of calcareous spar, but when from water of a higher temperature, assumes the prismatic one of arragonite*.

* See a review of the present state of our knowledge in regard to dimorphous bodies, by Professor Johnston of Durham, in the 7th Report of the British Association for the Advancement of Science, in which the causes of dimorphism are discussed with much acuteness.

CHAPTER IX.

Size or volume of the atoms considered.—Kopp and Schröder on atomic volume.—Playfair and Joule on the atomic volume of bodies, as compared with water.

IN the preceding chapter it was shewn, that there is no reason for supposing the atoms of different bodies to be distinguished from each other in respect to figure, but that whatever may be the crystalline form, or forms, which they severally conspire to produce, it is most probable that they are themselves in all cases spherical.

But it still remains to be considered, what may be their relative magnitude or volume, for as the hypothesis we have adopted assumes, not that the atom is the minutest conceivable portion of matter, but only that it denotes the extreme limit to which its division can be carried, it is quite consistent in us to suppose, that this limit may differ

in the several simple bodies, or even in each compound that is produced by their union.

That in every case however the divisibility of matter is such as to baffle all our powers of conception, will appear from a few very simple calculations.

Dr. Thomson has shewn, that an atom of lead cannot exceed in weight the $\frac{1}{310,000,000,000}$ th of a grain, and that the sulphur united with it in the form of sulphuret could not be more than $\frac{1}{2,015,000,000,000}$ of the same*.

* The following are the data upon which this calculation proceeds.

1 grain of lead was dissolved in 500,000 grains of water, and then converted into a sulphuret by passing through it a current of sulphuretted hydrogen gas, which rendered the whole of the water sensibly discolored. Now a quantity of water equivalent to about 1 grain may be so spread out as to cover a square inch of surface, and $\frac{1}{1,000,000}$ of a square inch may be distinguished under the microscope. Hence the water could be divided into 500,000,000,000 parts, every one of which would shew the presence of lead, and as the lead in a grain of nitrate of lead weighs only 0.62 gr., an atom of lead cannot weigh more than 310,000,000,000, whilst the atom of sulphur which rendered it visible cannot on the same principles exceed 2015,000,000,000 of a grain.

It may be also proved, that a square inch of gold is divisible into a million of parts, visible through a common microscope, so that when this metal is reduced to the thinness of leaf, $\frac{1}{50,700,000}$ th of a grain of it may be distinguished. Nor is this all, for as a grain of gold, of the thinness which it is on gilt silver wire, will cover an area of 1400 square miles, it follows, that $\frac{1}{1,400,000,000}$ th of a grain may be seen through a common glass. Yet it is probable, that even such a minute quantity comprehends a considerable number of atoms.

The contemplation of the animal and vegetable kingdoms supplies us with even stronger proofs of the great divisibility of matter—for when we recollect, that the smallest animalcule, whose existence is revealed to us by the highest powers of our best microscopes, must contain myriads of blood corpuscles, each consisting of several component parts, some of which bear a very small proportion to the rest, and which are yet uniformly diffused throughout the aggregate, it is probable, that the extreme limit to the divisibility of matter has not been reached, even by such a calculation as that entered into above.

Of this, indeed, Lucretius was aware, even before the microscope had revealed a new world of

274 *Comparison between the atoms of bodies*

animated beings not cognisable to our unassisted senses, as appears from the following lines of his Poem :

Primum, animalia sunt jam partim tantula, ut horum
Tertia pars nulla possit ratione videri.
Horum intestinum quodvis quale esse putandum est ?
Quid cordis globus, aut oculi ? quid membra ? quid artus ?
Quantula sunt ? quid præterea, primordia quæque,
Unde anima, atque animi constet natura necessum est,
Nonne vides, quam sint subtilia, quamque minuta ?

LUCRET. IV. 115.

How much more must the force of these reflections be felt, since the discoveries of Leuwenhoeck, of Schleiden, and of Ehrenberg !

Yet we must assume, that every one of these atoms is surrounded by its own atmosphere of heat, and is thus kept apart from those in its vicinity ; so that it is probable, that even in the compactest body, the portion of space actually filled by the atoms of which it consists, bears but a small proportion to the void spaces which are left between them.

Indeed, to adopt an illustration which was first suggested by a professor at Tubingen, and which has been adopted also by the French chemist Monsr. Dumas, we may liken the particles composing a solid, to the different suns, with their attendant planets and satellites, which are dispersed through that portion of space to which our

powers of observation extend, and which are supposed by astronomers to constitute parts of the same sidereal system.

And as such a comparison, if it should have no further use, may tend to dispossess our minds of the deep-rooted, though erroneous impression, that the particles of matter are, as they seem, in actual contact—an idea, which has been the parent of so many crude theories, as to the collision, entanglement, &c. of its minute corpuscles—it may be worth while to pursue it a little further into its details.

Divided then, as the celestial bodies mutually are, by vast regions of space, they yet are capable of acting upon each other, and are maintained at the same relative distances for ever, by virtue of their mutual attraction.

What gravitation is to them, cohesion is to the atoms of which they are severally made up.

Although they consist of particles, as inconceivably great in point of number, as they are minute in respect of size, these particles are indissolubly chained to the system of which they constitute a part, so that the entire mass is as indestructible, and in one sense as indivisible, as any one of its constituent atoms.

Hence, every member of our sidereal system remains unchanged and unchangeable, until the

sentence of the same Divine Being, which first called it into existence, has gone forth against it, and doomed it to annihilation.

It is inconsistent with the attributes of its omnipotent Author to suppose, that until that Word has been issued, its properties can ever alter, or the limits which He has assigned to it, either on the side of the *great* or the *small*, can in the slightest degree be transgressed.

Viewed from an immense distance, it is conceivable, that the whole mass of the sidereal system, with its suns, its planets, and their attendant satellites, might seem blended into one compact mass, so as to be regarded by the observer as one of innumerable such systems scattered through the regions of space—as “atoms of intensest light,”—to use the words of a recent poet; just as the particles composing a crystal, although separated one from the other by their respective atmospheres of heat, and influencing each other at a distance by the force of cohesion, appear to the eye as if in actual contact.

This same comparison may perhaps also convey to us a clearer conception of Dumas' Theory of Chemical Types, which was discussed in the two last chapters of the present work.

Just as any of the planets might be replaced in the solar system by a ball of matter of totally

IX. *and the members of the same sidereal system.* 277

different properties, provided its gravitating mass remained the same, without disturbing in the least the conditions of mechanical equilibrium; so in an organic substance, elements of the most diverse characters may be substituted for each other, and yet the molecular groups remain unaltered in structure and physical constitution.

In one respect, indeed, the analogy may appear to fail, for although the particles composing any one of the members of a sidereal system are chained down to their respective *foci* of central attraction, yet within the limits assigned to them they are continually shifting their position, and giving rise to an endless variety of products, so that change is as much the characteristic of the one, as immutability seems to be of the other—

Nam certe non inter se stipata cohæret
Materies; quoniam minui rem quamque videmus,
Et quasi longinquo fluere omnia cernimus ævo,
Ex oculisque vetustatem subducere nostris;
Quom tamen incolumis videatur summa manere;
Propterea, quia, quæ decedunt corpora quoique,
Unde abeunt, minuunt; quo venere, augmine donant:
Illa senescere, at hæc contra florescere, cogunt.
Nec remorantur ibi: sic rerum summa novatur
Semper, et inter se mortales mutua vivunt.
Augescunt aliæ gentes, aliæ minuuntur;
Inque brevi spatio mutantur sæcla animantum,
Et, quasi cursores, vitæ lampada tradunt.

LUCRET. II. 65—77.

Yet even here we may perhaps be assuming a greater amount of knowledge than is actually at our command.

If the particles into which heat is capable of resolving matter, when it assumes the gaseous condition, be themselves divisible into still minuter ones under the influence of chemical affinity, and if even the latter perhaps are composed of groups of atoms, rather than of single ones, it is conceivable, that every one of these groups, within its own little world, should admit of such an alteration in the position of its respective particles, as may serve to affect the properties it possesses, and consequently its relations to other bodies, although no one of these particles can separate itself from the group of which it constitutes a part.

And so with respect to magnitude—as the solar system, although definite both as to dimensions and weight, may not correspond in either respect with any of the stars associated with it in the same sidereal system; so likewise it is quite allowable to suppose, that the atoms of a simple body, although they may be unsusceptible of the smallest change in point of size from the beginning to the end of time, should nevertheless differ materially in each case from those of every other.

And this would appear a necessary inference, if

we assume that the force of gravitation is common to all matter as such, since on this assumption, the weight of a body must be regarded as a property, not varying in degree according to the nature of the substance itself, but determined by the quantity of matter comprised within a given compass.

Hence, supposing that all bodies were of the same specific gravity, the atomic weight of each would represent the relative size of its atoms, or in other words, its atomic volume*.

But before we proceed any further in this inquiry, it will be necessary to define in what precise sense we employ this latter expression, as, strictly speaking, the term would imply the amount of actual space occupied by the particle itself, which, being destitute of pores, we presume to be unalterable, both as to size and figure; whereas recent writers on the subject appear to understand it, as indicating the space occupied, or kept free from the access of other matter, by the material atom itself, together with its investing atmosphere of heat †.

* See an excellent account of the various Researches on Atomic Volume, by Professor Otto of Brunswick, translated by the Cavendish Society, and included in the first volume of their Reports, 1848.

† In order to avoid this ambiguity, Otto employs the term

Granting, indeed, that the latter always bore the same proportion to the atom which it encircles, it might be immaterial which view we adopted, but as the specific heat is liable to change, not only with the temperature, but likewise with the condition of the body itself, the latter hypothesis evidently admits the possibility of a change in the atomic volume, which the former excludes.

Accepting the term however in the sense of the space occupied by a particle of matter, and by its surrounding atmosphere of heat, it is evident, that supposing A and B to possess the same specific gravity, and the atomic weight of A to be six times greater than that of B, its atoms, with their investing atmospheres of heat, must be six times more bulky.

equivalent volume instead of *atomic volume*, while Gmelin prefers to calculate the number of atoms in a given space, rather than the space occupied by the atom, which will be conversely one of the other; so that whilst we obtain the atomic or equivalent volume, by dividing the atomic weight by the specific gravity, we get at the number of atoms, or the atomic number, as Gmelin styles it, by dividing the specific gravity by the atomic weight. But provided we define our meaning, the term *atomic volume* need not lead to any ambiguity, and seems preferable, as being more commonly received into the language of chemistry.

Hence it follows, that the atomic volume of a body may be calculated by dividing its atomic weight by its specific gravity.

Thus, taking hydrogen as our standard, and assuming the weight of its atom as 1, and that of the atom of oxygen as 8, it will follow, that as the specific gravity of the latter is 16, the volume of its atom as compared with hydrogen taken as unity will be $\frac{8}{16} = 0.5$, or, in other words, that the volume of the hydrogen atom will be twice as great.

Since, however, every volume of oxygen is supposed to contain 2 atoms, the specific gravity of its atom must be calculated at half that of its volume, and consequently the atomic volume will be the same as that of hydrogen.

Dumas appears to have first pointed out, and Thomson in this country first called attention to, the fact, that the same parallelism extends to azote and to chlorine.

Proceeding upon the above method of calculation, Kopp, a distinguished philosopher of Giessen, has given us the following numbers as representing the atomic volumes of various simple bodies :

Name.	Atomic weight.		Specific gravity.		Atomic volume.
Antimony	1613	...	6.72	...	240
Arsenic	937.5	...	5.86	...	160
Bismuth	2660	...	9.85	...	270
Bromine	1000	...	3.06	...	326
Cadmium	696.7	...	8.60	...	81
Chlorine	443.2	...	1.38	...	320
Chromium	328.5	...	5.10	...	64
Cobalt	368.5	...	8.39	...	44
Copper	396	...	9.00	...	44
Cyanogen	325	...	1.03	...	315
Gold	2458	...	19.10	...	128
Iodine	1585.5	...	4.93	...	320
Iridium	1232	...	21.60	...	57
Iron	350	...	7.70	...	45
Lead	1294	...	11.35	...	114
Mercury	1250	...	13.60	...	92
Molybdenum	596	...	8.68	...	68
Nickel	369.3	...	8.41	...	44
Osmium	1242.5	...	21.80	...	57
Palladium	665.5	...	11.70	...	57
Phosphorus	392	...	1.77	...	222
Platinum	1232	...	21.60	...	57
Potassium	489	...	0.84	...	583
Rhodium	652	...	11.40	...	57
Selenium	495	...	4.30	...	115
Silver	1350	...	10.40	...	130
Sodium	290	...	0.99	...	292
Sulphur	200	...	1.99	...	100
Tellurium	802	...	6.26	...	128
Tin	735.3	...	7.28	...	101
Titanium	301.5	...	5.33	...	56
Tungsten	1188	...	17.10	...	70
Zinc	406	...	6.95	...	58

Schröder, however, another German philosopher who has devoted much attention to this subject, conceives, that in order correctly to determine the relative atomic volume of different bodies, we ought to estimate it in each instance at such temperatures as are at corresponding distances from their respective fusing points, because the atmosphere of heat surrounding each will increase in proportion as it approaches that degree, and thus its specific gravity, one of the elements of the calculation, will vary.

Proceeding upon this principle, which however is a somewhat arbitrary one, and can hardly be shewn to rest upon any correct principle*, he has presented us with a table of atomic volumes, in a few cases differing widely from that of Kopp, but at the same time, with such numerous coincidences, as lead us to hope, that some general law on the subject will hereafter be elicited.

* For if the specific gravity of a body diminishes at a certain rate from the point of the actual privation of heat up to that at which it becomes liquid, each body would have a particular rate of expansion according to the distance of its fusing point from zero, nor does it appear on what principle we are to proceed, in order to determine the grade in the scale of the thermometer for one body which should be deemed equivalent to a given temperature in another.

284 *Kopp & Schröder's numbers compared.*

Thus the atomic volume of

	According to	
	Schröder.	Kopp.
Arsenic	156	160
Bromine	368	326
Cadmium	80	81
Chromium	72	64
Cobalt	44	44
Copper	44	44
Iridium	52	57
Lead	112	114
Molybdenum	68	68
Mercury	88	92
Nickel	44	44
Palladium	52	57
Phosphorus	220	222
Platinum	52	57
Silver	128	130
Tellurium	128	128
Tin	100	101
Titanium	56	56
Tungsten	68	70
Zinc	56	58

In two instances Kopp's numbers seem either to be a multiple of Schröder's, or to approach to it.

Thus the atomic volume

	According to	
	Schröder.	Kopp.
Of Gold	$64 \times 2 =$	128
— Bismuth	$128 (\times 2 = 256)$	270

In 5 instances only there is an entire discrepancy, viz.

	Schröder.	Kopp.
In Bromine	368	326
— Chlorine	240	320
— Iodine	424	320
— Potassium	240	583
— Sodium	128	292

But it may be asked, what end is to be answered by this enumeration of the relative atomic volumes of different simple bodies?

The weight indeed of the atoms supplies an useful key to their combinations, as well as to their mutual relations, and the specific gravities are likewise of general utility to chemists in their investigations; but their volumes, calculated upon the above data, do not admit of being appealed to in practice, and therefore, it may be said, might be just as well expunged from our treatises.

Nevertheless, in an essay like the present, intended to exhibit such glimpses, as the present state of our knowledge enables us to obtain, of the intimate constitution of matter, and of the general laws which bind together its minute corpuscles, it may not be irrelevant to point out the numerical relations as to atomic volumes, which seem to subsist, either betwixt the elementary bodies themselves, or betwixt any one of them and the compounds they produce.

Now with respect to the relations between the several elementary bodies, it may be observed, first, that the numbers representing their atomic volumes, as laid down by Schröder, are all multiples of 4, so that they appear to stand in a very simple relation one to the other.

Secondly, that whether we prefer the numbers

286 *Bodies whose atomic volume is similar*

given by Kopp or by Schröder, several bodies in the list either possess the same atomic volume, or one nearly approximating, and that in such cases it is commonly found that those so connected produce isomorphous combinations.

The following table, in which the numbers given are Kopp's, from which those of Schröder (as we have seen) vary a little, will illustrate this fact:—

Cobalt	44	Tungsten	70
Copper	44		
Iron	45	Selenium	115
Manganese *	44	Sulphur	100
Nickel	44		
		Gold	128
Iridium	57	Silver.....	130
Osmium	57		
Palladium	57	Bromine	326
Platinum.....	57	Chlorine	320
Titanium.....	56	Cyanogen	315
Zinc	58	Iodine	320
Chromium	64	Potassium .. (292 × 2)=	583
Molybdenum	68	Sodium	292

Now it will be observed, that the bodies, whose atomic volume is represented by the numbers 44 or 45, are all isomorphous; so also are the four bodies whose atomic volume approaches to the numbers 320; and that the atomic volume of potassium, a base which is isomorphous with sodium, is just a multiple by 2 of the number assigned to the latter.

* This one is Schröder's estimate.

Hence one of the conditions, by which similarity of crystalline form, and analogy of chemical properties, are determined, would seem to be an agreement in the volume of the atoms of which the respective bodies are severally composed.

It is indeed natural to suppose, that unless the atoms themselves are of the same or nearly of the same magnitude, the resulting bodies must be of different forms, and that otherwise no substitution of one element for another could take place, without affecting materially the character of the crystallisation.

Nevertheless it must be remarked, that several other bodies, regarded as isomorphous with the group at the head of which stands cobalt, possess different atomic volumes, such, for instance, as zinc, cadmium, and chromium; and on the other hand, that there is no close numerical relation between the members of some of the best-defined isomorphous groups—such, for instance, as arsenic, antimony, and phosphorus.

It has been suggested indeed by Kopp, that isomorphous compounds may arise, where the elements themselves have not the same atomic volumes; and this for two reasons—first, because the atomic volume may alter when a body enters into combination, and secondly, because the dif-

lation of the atomic volumes of the several simple bodies to those of the compounds which they produce, it may be remarked, that various attempts have been made with greater or less success, to follow up, in the case of solids and liquids, the same line of research, which Gay-Lussac carried out in so beautiful a manner with respect to bodies in a gaseous condition.

It will be recollected, that when two gases unite, their volume sometimes remains unchanged, as in the case of chlorine and hydrogen; sometimes becomes less, as in the case of hydrogen and oxygen; sometimes, though more rarely, greater, as in that of the vapours of sulphur and of mercury, where the resultant occupies more space than its constituents put together.

In both these latter instances it has been shewn, that the change of volume bears some numerical relation to that which it possessed previously.

In like manner Schröder has laid down the following principles with respect to solids and liquids, as the result of his own elaborate researches into their atomic volumes.

He assumes as a first principle, that the atomic volume of a compound must be the sum of that of its elements*, but he contends nevertheless that

* Since this chapter was prepared for the press, I have

in many instances, a body in entering into union with another undergoes a change in its atomic volume, just as a dimorphous body becomes of a different specific gravity, when it passes from one crystalline form to another.

The new atomic volume assumed always however stands in some numerical relation to the original one, namely as the numbers 1, 2, 3, 4, 5, 6, &c., and isomeric bodies may be produced by the

lighted upon a very interesting paper by professor James Dana published in Silliman's American Journal for March last, in which it is maintained, that if the principle assumed in the text by Schröder be admitted, no correspondence can be shewn to exist between the atomic volumes of isomorphous minerals; but on the other hand, if, instead of calculating the atomic volume, by regarding it as the sum of that of its constituents, we divide the latter by the number of atoms of acids and bases present, a nearer approach to a correspondence is perceived, and again one nearer still, if we divide the same by the number of atoms of all the elements present.

Thus serpentine, chrysoberyl, chrysolite, villarsite, Epsom salt, and picromine, are minerals that crystallise alike, yet there is no similarity in constitution between them, for chrysoberyl, for example, contains only 2 atoms of acid and base, and 7 of elements; and serpentine 19 of the former and 46 of the latter; and accordingly the atomic volume, as deduced from the sum of the atomic volumes of their respective constituents, shews no correspondence, or if any, one only of multiple relations.

But if the atomic volumes are divided by the number of atoms, either of the acids and bases present, or of their re-

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change in volume which the same atom undergoes under different circumstances.

spective elements, a nearer accordance is perceived, especially in the latter instance.

I will just illustrate this by two instances :

Serpentine.

4 $\ddot{\text{Si}}$ atomic weight*	$577.31 \times 4 = 2309.24$
9 $\ddot{\text{Mg}}$	$254.50 \times 9 = 2290.50$
6 Aq.	$112.50 \times 6 = 674.88$

Specific gravity	2.5)	5274.62	aggregate atom. weight.
Number of atoms of acid } and bases present }	19)	2068.5	aggregate atomic vol.
		109.	

Number of atoms of elements present	46)	2068.5	aggregate atomic vol.
		44.95	

Epsom salt.

1 $\ddot{\text{S}}$	500
1 $\ddot{\text{Mg}}$	254.50
7 Aq.	787.36

Specific gravity	1.75)	1541.86	[aggregate. atomic weight of the
Number of atoms of acids } and bases present }	9)	881.0	aggregate atomic vol.
		98	

Number of atoms of elements	20)	881.0	aggregate atomic vol.
		44.0	

Proceeding upon these principles, the following will be the numbers obtained in the case of the above 6 isomorphous minerals, calculated ac-

* The atomic weights are calculated according to the Berzelian standard.

The compounds of sulphur and of copper afford instances of both these laws.

In the case of the sulphuret ($\text{Cu} + \text{S}$) the atomic volume is 144, which is exactly that of 1 atom of copper = 44 + 1 atom of sulphur = 100; whereas, in the disulphuret, ($\text{Cu}_2 + \text{S}_2$) the atomic volume is

cording to the foregoing method, in which A gives the aggregate atomic volume; B, the aggregate divided by the number of atoms of acid and base; C, ditto, divided by that of the atoms of the elements—

	A	B	C
Chrysoberyl $\text{Be } \ddot{\text{Al}}$ —New atom. weight	216.18	108.9	30.90
Old atom. weight	1300.9	185.8	37.16
Von Kobell's } ..	433.7	144.6	36.14
atom. weight }			
Chrysolite $\ddot{\text{Si}}, 2 (\frac{2}{11} \text{Mg}) \ddot{\text{Fe}}$	416.	104.0	41.60
Villarsite $4 \ddot{\text{Si}}, 12 \ddot{\text{Mg}}, 3 \ddot{\text{H}}$	1916.3	100.86	41.65
Serpentine $4 \ddot{\text{Si}}, 9 \ddot{\text{Mg}}, 6 \ddot{\text{H}}$	2068.5	109.0	44.90
Epsom salt $1 \ddot{\text{Si}}, 1 \ddot{\text{Mg}}, 7 \ddot{\text{H}}$	881.0	98.0	44.00
Picrosmine $4 \ddot{\text{Si}}, 6 \ddot{\text{Mg}}, 3 \ddot{\text{H}}$	1588.7	122.0	46.68

From these facts Dana draws, amongst other conclusions, the following, namely, that the atoms of elements composing a given compound are not combined together, since, if they were, the atomic volume of the aggregate ought to be that of the compound, but that the atoms influence each other by their mutual approximation, in such a manner, that each one undergoes a change, and the actual atomic volume consequently is a mean result of the molecular forces set in action.

166 instead of 188, as it ought to be, in order to correspond with the sum of its elements, viz. :

$$\text{Cu } 44 \times 2 = 88 + \text{S } 100.$$

Hence, in this instance, a condensation has taken place equal to 22, or $\frac{1}{4}$ th of the atomic volume of the copper.

In other cases the atomic volume of the compound is much smaller even than that of one of its constituents.

Thus, oxide of potassium has an atomic volume of 222, whereas potassium itself has one of 583, if calculated according to Kopp's method, and of 240, if after that of Schröder.

In a few cases the contrary law prevails, the atomic volume of sulphuret of arsenic being 375, whereas the sum of the atomic volumes of its two ingredients, sulphur and arsenic, is only 360, viz.

$$160 + 100 + 100.$$

Professor Otto, however, in his abstract of these researches, seems to have successfully exposed their unsoundness, and to have shewn, that they are more liable to objection, than those which Schröder had originally suggested, and of which Kopp likewise had availed himself in his disquisitions on the same subject.

The law which Schröder had previously arrived at, with respect to the relation between the atomic

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volumes of compound bodies, may be stated as follows :

If from the atomic volume of compounds which contain a common ingredient, as for example oxygen, we subtract the atomic volume of the other constituent, the number that remains will be equal.

Thus oxide of copper ($\text{Cu } 1 + \text{O } 1$)

having an atomic volume of	77.5
and copper having one of	44.0

there remain for that of oxygen	33.5
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and

oxide of iron $\text{Fe } 2 + \text{O } 3$

has an atomic volume of	191.5
iron having one of	90.0

there remain for 3 atoms of oxygen	101.5
for 1 atom	33.8

So that it would appear, as if, whilst the metal retained its own atomic volume unchanged, the oxygen was in each instance condensed, so as to possess the atomic volume of about 33.

Kopp admits, that this doctrine of Schröder's applies to all the heavier, but contends, that it fails with respect to the lighter metals.

Thus potassium in its compounds has an atomic volume different from what it possesses when isolated, the atomic volume of potassium being

583, but when converted into potass, and united with sulphuric acid, forming a salt having the atomic volume of only 420.

Kopp has calculated the atomic volume which these lighter metals, viz. ammonium, barium, calcium, magnesium, potassium, sodium, and strontium, have, when they enter into combination, and finds, that it is the same in all the compounds they form.

This change in atomic volume, in passing from an uncombined state to one of combination, is regarded as a case of dimorphism, for in dimorphous bodies, as the specific gravity alters, the atomic volume must undergo in like manner a corresponding change.

In the case of liquids, Kopp found, that analogous compounds exhibit similar differences in respect to their atomic volume; thus, the numbers, expressing that of acetic acid, are 708.7; that of acetic ether (an acetate of ethyle) 1243.5, difference 534.8; that of the acetate of methyle 1012, difference 303.3; which are in accordance with the fact, that the combinations of ethyle have an higher atomic volume than those of methyle.

Thus, that of alcohol is 729.9, that of pyroxylic spirit 503.3, difference 226.6; whilst hydrated

acetic acid is 708.7, hydrated formic acid is 466.8, difference 241.9; and whilst acetate of ethyle is 1243.5, acetate of methyle is 1012, difference 231.5.

Thus then, in consequence of the number of atoms compressed into one being greater in ethyle than in methyle, the former, as we have seen, being $C_4 H_5$, the latter $C_2 H_3$, their respective combinations possess different atomic volumes.

Kopp has pointed out a curious relation between the atomic volumes of water, alcohol, and ether, taken at their respective boiling points.

That of water is calculated at 117.1, of ether at 663.3. Now these numbers added together give exactly 780.4, which is the atomic weight of alcohol, a compound of ether and of water.

The above numbers, it is to be remarked, are all simple multiples of 39; water by 3; ether by 17; alcohol by 20: viz.

$$\begin{array}{rcl} 39 + 3 & = & 117.1 \text{ atomic volume of water} \\ 39 + 17 & = & 663.3 \text{ ————— ether} \\ 39 + 20 & = & 780.0 \text{ ————— alcohol} \end{array}$$

Löwig indeed has pointed out, that we are as yet far from having arrived at any general law applicable to all cases on this subject, yet even he

admits, that in liquids of organic origin, which have similar rational* formulæ, the atomic volume is based upon some principle of regularity.

For example, it cannot be a matter of accident, when we find at their respective boiling points :

wine spirit C ₄ H ₆ O ₂ with an at. vol. of 780	
wood spirit C ₂ H ₄ O ₂	528
difference	252

coincident with one in atomic constitution = C₂ H₂.

fusel oil C ₁₀ H ₁₂ O ₂ with an at.vol.of 1529	
wine spirit C ₄ H ₆ O ₂	780
difference C ₆ H ₆	749

or C₂ H₂ × 3 and 252 × 3 = 756.

fusel oil C ₁₀ H ₁₂ O ₂	1529
wood spirit C ₂ H ₄ O ₂	528

Difference C ₈ H ₈	1001
or C ₂ H ₂ × 4 and 252 × 4 =	1008

* By *rational*, in contradistinction to, *empirical* formulæ, we mean expressions of the manner in which the respective atoms are combined or grouped together, and not merely of the number of atoms of each of the ingredients present. Thus SO₃+KO is the rational formulæ of the salt called sulphate of potass : S, O⁴, K the empirical.

So that C2 H2 augment the atomic volume always by a quantity = 252.

Assuming then 250 to represent the atomic volume of C2 H2, we shall get 500 for that of C4 H4, so that H2 O2 in alcohol will have added 280 to the atomic volume of that liquid, or H1 O1 = 140.

In like manner H2 O2 will have added 278 to the atomic volume of wood spirit, as will be seen by the following statement :

$$\text{C2 H2} + \text{H2 O2 wood spirit} = 528$$

$$\text{C2 H2 as above} \dots\dots\dots 250$$

$$\text{H2 O2} \dots\dots\dots 278$$

$$\text{C10 H12 O2 fusel oil} = \dots\dots 1529$$

$$\text{C2 H2} : 250 :: \text{C10 H10} : 1250$$

$$\text{leaving for H2 O2} \dots\dots\dots 279$$

Löwig however has shewn, that no such correspondence can be traced, when we compare together compounds of carbon and hydrogen having different rational formulæ.

The atomic volume of carbon, in wine spirit, wood spirit, and fusel oil, indeed corresponds, because they are homologous bodies, and it is on this account that the atomic volume of the carbon

in every one is 66 or 67* ; for as the atomic vo-

lume of $C_2 H_2 = 250$

and consequently of $CH = 125$

the atomic volume of H being 58.5

there remains for that of C 66.5

If however we deduce it from other hydrocarburets, it will be found that it amounts to 90, 82, 78, and 34, according to the substance taken as our standard, so that it is plain, that the volume of an elementary atom cannot occupy the same space in all the compounds into which it enters.

Yet even here a certain relation may often be traced between numbers representing the atomic volumes of the component parts as in the three organic radicals, ethyle, methyle, and amyle ; for in ethyle the volumes of carbon and hydrogen are to each other as 6 to 1 ; in methyle as 3 to 1 ; and in amyle as 2 to 1.

Schröder moreover has endeavoured to trace a

* The atomic volume of water (HO) at its boiling point being 117, it follows that H is 58.5, and O 58.5, assuming (as has been done above) that the atomic volumes of H and O are equal.

connection between the expansion by heat of solid bodies, and their atomic volumes.

Thus lead expands between 0° and 100° six times as much as platinum, and its atomic volume is twice as great, the atomic volume of platinum being 57

of lead..... 114 or $57 + 2$

Thus the expansion and the equivalent volume are respectively as 2 to 6

and as 1 to 3.

The specific heat of the same body varies in combination, but this also, according to Schröder, observes a fixed law.

Thus, in oxide of tin the specific heat of the oxygen is 23.5, which is only $\frac{1}{4}$ ths of 30, its ordinary specific heat.

But in oxide of tin the atomic volume of the oxygen is only 16.7, or about the half of that in which it exists in copper, zinc, mercury, iron, and other metals, where it is found to approximate to the number 33, so that the equivalent volume has diminished $\frac{1}{2}$.

the specific heat $\frac{1}{4}$.

Thus the specific heat

of iron pyrites ($\text{Fe } 2 \text{ S}$) is 97

of iron..... 40

of sulphur 2 atoms..... $\overline{57} :: 1 : 28$.

Hence spec. heat of sulphur, when free, is 40.
that of ditto in combination is28.5
or about $\frac{2}{3}$ of the former.

Atomic volume of iron pyrites	= 147
of iron	45

leaving for sulphur 2 equiv. 102, or 1 = 51.

Now the atomic volume of sulphur being 100, it is diminished in combination to $\frac{1}{3}$, so that here too the same law prevails.

It may be noticed, as an indication of the speculative tendency of the German mind, that all the researches of which I have presented this brief abstract emanate from that nation, and it has been justly remarked by M. Marignac, in the able review he has given of them*, that without disparaging their utility, or underrating the importance of the relations they appear to have disclosed, namely, the connection between the specific gravity of bodies and their chemical constitution, and between isomorphism and an equality of atomic volumes, we must regard the precise laws which they have attempted to lay down as uncertain, until an exacter knowledge of the specific

* Bibliothèque universelle de Geneve, 1846.

gravities of a greater number of bodies has been acquired.

“When Berzelius propounded,” (or rather gave the sanction of his great name,) “to the doctrine of chemical equivalents, it would not have been adopted so promptly by the chemical world, if he had contented himself with shewing, that the theory was to a great degree in accordance with the majority of the analyses which could then be appealed to, and with rejecting those that did not bear out his principles.

“He did not pursue so easy a method, but personally undertook the examination of a vast number of compounds, and by the aid of the improvements he introduced into the modes of research then in use, shewed, that his theory was in entire accordance with experiment. Such is the model which we ought to imitate, if it be our aim to discover the laws which regulate the density of compound bodies.”

It is but justice to Messrs. Playfair and Joule, the only British chemists who have published any extended series of researches connected with the same subject*, to remark, that in accordance

* I except Mr. Herapath, who has published in the Phil. Magazine a paper on the same subject.

with the more practical character of their countrymen, they have gone to work experimentally, and instead of availing themselves of data supplied by others, as Kopp and Schröder appear for the most part to have done*, have determined for themselves the facts which they adopt as the basis of their subsequent calculations.

Their experiments indeed appear to have been extremely numerous and precise, and their plan of proceeding equally ingenious and simple.

It consisted in dissolving definite quantities of different salts in distilled water, noting, by the aid of a delicately constructed apparatus, how much, if at all, the volume of liquid became augmented in consequence; and the general result which they arrived at by this method was, that 9 = the atomic volume of water furnishes the standard, to which that of all other bodies in a state of solution bears a simple numerical relation.

The most striking fact, indeed, which came out in the course of their inquiry, was a verification of one, which the veteran Dalton, at the

* I have not been able to obtain all Kopp and Schröder's original papers, but from what I have seen of them, they appear to me to consist for the most part of calculations and deductions built upon data supplied by others.

close of his career, had announced with respect to sugar *, but which at the time scarcely obtained credence, namely, that when this substance is dissolved in water, the increase of volume in the solvent was just proportionate to the quantity of water preexisting in the substance dissolved, so that its other ingredient, carbon, had appeared to produce no sensible influence upon the bulk.

Messrs. Playfair and Joule have shewn, that the same takes place in several salts, inasmuch as, when they are dissolved in water, there is only such an increase of volume, as would be caused by the liquefaction of the water chemically combined with the salt.

In other cases there is an increase of volume beyond this, but always in the proportion of 9, or some multiple of 9, for each equivalent of the salt.

On the other hand, the volume of a salt in its solid state, estimated by introducing it into a saturated solution of the same, and by determining the increase in its volume resulting, appeared to be some number approximating either to 11, or else to 9.8.

Why these should be the numbers to which

* Cane sugar may be regarded as a compound of water 11 atoms, carbon 12.

the atomic volume of salts is referable, the authors explain as follows :

The atomic volume of water is 9, that of ice is 9.8 ; whilst the former, therefore, is the standard to which the volumes of bodies in a state of liquidity are referable, the latter holds the same place in respect to solids.

Now, as the eighth part of 9.8 is $= 1.225$, they assume this, as the number to which all other bodies are comparable, and they shew, that the atomic volumes of the salts are multiples of it, either by 8 or by 9 ; the former producing the numbers 9.8, the latter 11.

With regard to the metals also, they found their atomic volumes to be multiples of 1.225 by 3, 4, 5, and other whole numbers, or else by $6\frac{1}{2}$, $7\frac{1}{2}$, $8\frac{1}{2}$, &c., as the following table will indicate :

Table

TABLE

*Of the atomic volumes of the metals deduced from the experiments of Playfair and Joule, as also of those calculated by Kopp and Schröder, the two last being reduced to the same standard as that of the former: Where there is a manifest disagreement a * is attached.*

Name,	Playfair and Joule's		Kopp.	Schröder.	1/4th of the at. volume of ice.
	Atom. vol. by experiment.	Atom. vol. by calculation.			
Manganese ..	3.45 ...	3.67	45 = 3.40	44 = 3.52	3
Iron	3.59 ...	3.67	45 = 3.52	44 = 3.52	3
Cobalt	3.46 ...	3.67	44 = 3.52	44 = 3.52	3
Nickel	3.54 ...	3.67	44 = 3.52	44 = 3.52	3
Copper	3.56 ...	3.67	44 = 3.52	44 = 3.52	3
Aluminium ..	5.13 ...	4. 9	.....	60 = 2.40	4
Zinc	4.71 ...	4. 9	58 = 4.64	56 = 4.48	4
Cadmium	6.46 ...	6.12	81 = 6.48	80 = 6.40	5
Chromium ..	5.09 ...	4. 9	64 = 5.12	72 = 5.76	4
Bismuth	7.27 ...	7.35	270 = 21. 6	128 = 10.24	6
Tin	8.09 ...	7.96	101 = 8.08	100 = 8.00	6½
Arsenic	13.07 ...	13.47	160 = 12. 8	156 = 12.48	11
Antimony ..	19.21 ...	19.60	240 = 19. 2	.....	16
Molybdenum ..	5.56 ...	5.51	68 = 5.41	68 = 5.41	4½
Tungsten	5.45 ...	5.51	70 = 5. 6	68 = 5.41	4½
Titanium	4.59 ...	4.90	56 = 4.48	56 = 4.48	4
Tellurium ..	10.36 ...	10.41	128 = 10.24	128 = 10.24	8½
Lead	9.14 ...	9.18	114 = 9.12	112 = 8.96	7½
Mercury	7.24 ...	7.35	92 = 7.36	88 = 7.04	6
Silver	10.29 ...	10.41	130 = 10. 4	128 = 19.24	8½
Gold	10.34 ...	10.41	128 = 10.24	64 = 5.12	8½
Platinum	4.71 ...	4. 9	57 = 4.56	52 = 4.16	4
Palladium ..	4.88 ...	4. 9	57 = 4.56	52 = 4.16	4
Rhodium	4.70 ...	4. 9	57 = 4.56	56 = 4.48	4
Osmium	9.97 ...	9. 8	57 = 4.56	64 = 5.12	8
Tridium	4.71 ...	4. 9	57 = 4.56	52 = 4.16	4
Potassium ..	45.26 ...	45.32	583 = 66.64	240 = 19.20	37
Sodium	24.45 ...	24.50	292 = 23.36	128 = 10.24	20
Barium	17.17 ...	17.15	.....	144 = 11.52	14
Strontian	9.73 ...	9. 8	.....	104 = 8.32	8

The specific gravity of the metals was, however, found to vary, according to the condition in which they were obtained.

When in a state of compactness, they possessed in general an atomic volume less by about $\frac{1}{10}$ th, than when in a state of fusion, or of fine division.

The authors also confirm the difference in point of atomic volume, of which dimorphous bodies are susceptible.

Carbon, for instance, differs in this respect, according as it is in the state of charcoal, of graphite, or of diamond.

Like the metals, it is always a multiple of 1.225, but in the first of these conditions, by 5 : in the second by 4 ; and in the third by 3.

In accordance with this view, it is suggested, that the difference between the specific gravity of calc-spar and of arragonite may depend upon the circumstance, that the carbonic acid in the one is derived from charcoal, in the other from graphite.

Such are the principal conclusions deduced by Messrs. Playfair and Joule from the very elaborate train of experiments which they have undertaken.

For the objections made to their conclusions

by M. Marignac, on the ground, that the authors do not appear to have taken into account the difference of atomic volume belonging to a salt at different temperatures, and that they have selected in some cases, without any certain rule, that which best accorded with their hypothesis—as also from our ignorance of the right proportions of salt and water, which ought in each instance to be employed in order to obtain comparable results—I shall refer to the Memoir in the *Bibliothèque universelle de Genève* already quoted.

It must, I think, be admitted, that there seems something rather arbitrary in the assumption, sometimes of the numbers 11, and at other times of 9.8; as those of which all other atomic volumes are to be regarded as multiples, and it is at least evident, although upon this I should lay but little stress, that Schroeder's law, as to their being all multiples of 4, must in such case be abandoned, as the two are incompatible.

At the same time, the precision of the method by which the specific gravities were determined, and the character for skill and exactness belonging to the experimentalists themselves, are circumstances, which inspire us with greater confidence in their experiments than in any preceding

ones, and incline us to adopt in preference their results.

The absolute disappearance of the carbon in the estimate given of the atomic volume of sugar, &c., is however a fact at present not reducible to any known principle.

Of course, by the *disappearance* of the carbon can only be meant, that the atom of water had contracted in volume just in proportion to the amount of carbon added, or that it had received the carbon within its interstices, without having its volume in consequence enlarged.

But even this view of the phenomenon is encumbered with many difficulties, for in all former cases brought before us, although the atomic volume of a body in combination might change, yet it did not disappear, and accordingly, whilst we admit the fact on the authority of such expert experimentalists, we still look for some further elucidations, by which it may be referred to the general principles of the science.

The above remarks on Atomic Volume may appear perhaps in the light of a digression from the main subject of this Essay, but an inquiry into the intimate constitution of matter would scarcely be complete, if it did not embrace the

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consideration of all the properties which are ascribed to its ultimate molecules.

The discussion of the facts relating to this question has at least proved to us, that the external form, as well as the chemical characteristics, of a body, stand in some intimate relation to the size or volume of its atoms, although after estimating to the full the importance of this circumstance, an ample margin seems to be still left for other influencing causes.

The form of the particles cannot be amongst the number of these, for it is probable, that they all alike are spherical, and even if they varied in figure, that circumstance would afford no clue to the different properties of the bodies which they conspire to produce.

But that they mutually affect each other, in some unexplained manner, according to the mode of their collocation, seems to be implied, by the great diversity of properties belonging to the compound radicals, although formed of common elements; and still more by the existence of bodies which are possessed of different properties, although similarly constituted, both as to the nature and the proportion of their component parts.

CHAPTER X.

ON THE LAWS REGULATING THE COMBINATIONS BETWIXT THE ATOMS OF BODIES.

Chemical attraction counteracted, both by cohesive and by adhesive attraction—difference between the two—Physical and mechanical influences modifying chemical affinity—Views with respect to chemical combination which were entertained by Lavoisier now superseded by others—Graham's doctrine with respect to the office of water when in union with acids and with bases—Binary theory of salts considered—Decomposition not always accompanied with chemical combination—Catalytic action considered—Various phenomena referred to this supposed principle—Liebig's explanation of some of these facts—as in the case of fermentation—Cagniard de la Tour's theory of the same—Changes that occur in starch referred to a similar cause.

IN the preceding chapters of this work it has been my intention to shew, that matter is made up of a congeries of particles, which must have continued the same both as to form and magni-

tude from the first moment of their creation, inasmuch, as it is assumed that no natural agent is capable of severing their parts asunder; but that their relative magnitude or volume must vary, in the case of simple substances according to their nature, and in the case of compounds according to the proportion, as well as according to the character, of the ingredients which contribute to their formation.

It was further suggested, that the properties of atoms may in each case be modified at least, if not determined, by their collocation or grouping, so that the mechanical condition of a body may be in some sense regarded as the indirect cause of its chemical, as well as of its physical constitution.

But whatever conjectures we may indulge in with reference to this question, it must be admitted as a matter of fact, that the particles of each elementary body are distinguished from those of every other, not only by their relative size and volume, but likewise by the force of their mutual attraction, and of their affinities for the particles of other substances.

That these forces, indeed, or rather their outward manifestations, bear some reference to the molecular constitution of the body, is shewn even

in simple bodies from the phenomena of *allotropism**, whilst that in compounds the attractions are weakened, enhanced, and modified, in a variety of different ways, not only by the bringing together of particles of different kinds, but likewise by their very collocation and arrangement, may be inferred, from the new substances produced by the union of two elements, and from the various isomeric bodies that may be evolved from the same particles differently grouped.

Nevertheless, the ultimate fact remains, that a certain amount of cohesion and of chemical attraction must be regarded as the attribute of every one of the particles of matter, and hence it becomes my business to consider in the next place the nature of these two forces, and the manner in which they affect the various bodies submitted to their influence.

It is evident in the first place, that although cohesive attraction varies infinitely in degree, it must always be inferior in point of force, under certain circumstances at least, to chemical attraction, for a substance, in which this was not the case, would of necessity remain to the end of time in a state of indifference to all others.

* For an explanation of this term see Additional Notes.

By cohesive attraction then we mean that force which binds together the particles of a body, and which, until it be overcome, effectually prevents their union with those of any other substance for which they possess an affinity.

As it takes place merely between *particles*, we must distinguish it from another force frequently confounded with it, which seems to bear the same reference to the masses of matter, which cohesive attraction does to its molecules.

The existence of such a force seems to be evinced in several well-known phenomena.

It is shewn, for instance, in the tendency which camphor and other volatile substances have, when they sublime, to collect around certain nuclei on the surface of the containing vessel, instead of spreading themselves equally throughout.

It is evinced also, if it be true, that an intimate mixture of finely comminuted clay and sand, such as is used in the common operations of pottery, cannot be left together for any length of time, without having the silicious particles collected in certain parts of the mass, more than in others.

This principle may also be called in to help us towards an explanation, of the nodules or concretions of one kind of stone, so frequently occurring in rocks of a different description—of agates and

other silicious concretions, for example, in crystalline rocks,—and perhaps also in some instances of the flints that occur in chalk; although we do not of course intend to exclude the influence of organized bodies, in determining a deposition of silica on their surfaces, through the disengagement of carbonic acid during the progress of their decay.

Is not the affinity of capillarity, as Chevreuil calls it*, a phenomenon of the same description? It is distinguished by him as the kind which acts solely between the *surfaces* of the attracting body and of that which combines with it—as, for example, between the particles of a dye, and the cloth, where the colouring matter bears no sort of proportion in point of quantity to the stuff which imbibes it; between the surfaces of a mass of spongy platina and the particles of a gas; or between the particles of carbon and iron united by the process of cementation into the form of steel.

In these cases, indeed, it may be said, that the division of the matter is carried to *so extreme* a point, as to lead us to infer that it may take place between its ultimate particles; but the

* See Appendix to Pelouze's Chemistry, vol. iii.

difficulty of supposing this consists in the *indefinite* nature of the combination, in its superficial character in some cases, and its irregular distribution in others—circumstances which lead us to surmise, that the union takes place in another manner, and on another principle, than that which is seen to flow from the operation of ordinary chemical affinity.

Let us however turn to some other instances, in which the operation of this force is perhaps even more plainly and decisively evinced.

The adhesion of smooth plates of glass or of metal, when brought into close contact, and the property of water, as well as of gases, to adhere to solid substances, which gives rise to the phenomenon of capillary attraction, and to the hygrometric power belonging to certain earths, may be accounted for upon the same principle; as an illustration of which I may mention a remarkable instance of the kind afforded me, when I visited Vesuvius in 1834, in the gradual disengagement of large volumes of muriatic acid, steam, and sal ammoniac, from cavities in the still incandescent lava, that had been emitted from the mountain several months before*.

* See my Memoir on Vesuvius in the Philosophical Transactions for 1834.

These volatile products could not by possibility be generated within the crevices of the lava from which I found them to be exhaled—they must have been entangled within its pores at the time it issued from the volcano; and when we consider the high temperature that at that time belonged to this viscid material, it would seem that some other force, besides that of the superincumbent pressure, must have contributed to their confinement.

The same phenomenon indeed is observed daily in the smelting of iron and other metals, where gaseous matter is so intimately mixed with the semifluid mass, as only to be extricated by a long and laborious process of kneading, &c.

In both instances, the property in question is most serviceable, in moderating the expansive force of the gases and vapours disengaged by the processes which are taking place, especially on the gigantic scale in which they are conducted within the recesses of a volcano. It is difficult indeed to estimate, what might have been the destructive energy of these gases, if, instead of being restrained, as by a safety-valve, within the pores of the semifluid mass which is ejected as lava, they had exploded at the very instant of their generation, carrying with them through the orifices of

the crater every thing which impeded their progress.

The curious manner in which gases appear in some cases to adhere to the surfaces of solid bodies, without actually combining with them*, enables us to explain the power, which certain solid bodies, such as platina, possess, of condensing on their surfaces gases, and thus determining a combination between them; for when we are told, that a cubic inch of a porous body like charcoal must have at the lowest calculation a surface of 100 square feet, and reflect, that platinum, in the spongy condition in which it is obtained, when precipitated from its solution in an acid, is at least equally honeycombed with interstices, we need not wonder, that the latter should be able to condense 800 times its volume of oxygen, and proportional quantities of other gases, thus bringing oxygen and hydrogen within the sphere of their mutual affinities, and causing them to unite.

* Nobili explained, on the same principle, those beautiful appearances which are presented by certain metallic plates, upon which, if immersed in acetate of lead whilst forming the positive electrode of the battery, the negative electrode being brought immediately above it, rings "caused by films of oxygen of different thicknesses, and, consequently, of different colours," make their appearance; but recent experiments have shewn, that the rings are in reality composed of peroxide of lead.

"In this manner," says Liebig*, "every porous body, rocks, stones, the clods of the fields, &c., imbibe air, and therefore oxygen, the smallest solid molecule being surrounded by its own atmosphere of condensed oxygen; and, if in their vicinity other bodies exist which have an affinity for oxygen, a combination is effected. When, for instance, carbon and hydrogen are thus present, they are converted into nourishment for vegetables—into carbonic acid and water."

To proceed to other instances. It was on this principle of adhesive affinity, that professor Daniell proposed to explain the ammoniacal amalgam formed by voltaic action, referring to the analogous case of the absorption of oxygen at a white heat by silver, which can only be supposed to exert an *adhesive* attraction for the gas, as it disengages it again on cooling; and it is in the same manner, that Schoenbein attempted to account for the insensibility of iron to the action of nitric acid, under certain conditions.

I conceive, that the circumstances, by which this singular kind of attraction is regulated, deserve a more full investigation, and that it is highly proper to distinguish it by a separate name

* Liebig's Chemical Letters, p. 17.

from the cohesive attraction subsisting between the particles of matter. Perhaps the term *adhesive attraction*, which has been already proposed for it would be sufficiently characteristic.

It has been questioned, indeed, (see Persoz, *Chimie Moleculaire*, p. 875,) whether this species of attraction is essentially different from that which we denominate *cohesive*, and it may very safely be conceded, that the primary cause of both will most probably turn out to be the same.

But so also may cohesive attraction itself, according to the ingenious generalization of Mosotti*, be included under the same law as that of gravitation, and the chemical affinities of bodies be regarded as the consequences of their physical properties, as Persoz has attempted to demonstrate†.

* See Scientific Memoirs, vol. i. p. 448.

† Persoz would seem to consider, that whenever the atoms of two contiguous bodies are brought by heat into that condition as to volume, that no physical obstacle exists to their union, a combination takes place between the two.—At common temperatures, for instance, carbon does not combine with oxygen, because the atomic volume is not such as to enable it to form a compound with the latter; but when heated, a portion is converted into vapour, which has an atomic volume calculated to occupy with the corresponding volume of oxy-

None of these hypotheses, however, even if they were more fully established, and more completely developed than they can claim to be, ought to prevent us from ranging under distinct heads, and treating as separate branches of science, these several phenomena, regarding the attraction which operates between masses of matter, distinct from that which takes place between their particles, as electrical attraction is from chemical affinity, or as the repulsive energy exerted by heat upon masses of matter, is from the same force which imparts an elastic condition to their particles.

In whatever light however we view these forces, they must be regarded as in their nature antagonistic to that which produces chemical combination, at least in all those cases where the attraction operates between the masses or the particles of the same body, since, so far as its influence goes, it must tend to prevent chemical union from taking place.

gen the space which belongs to the compound molecule of carbonic acid.

Thus the physical form, or type, of the atom would be the cause of the union between the two bodies.

This hypothesis however is purely gratuitous, and I do not see that much would be gained by adopting it.

The force which determines this latter effect, being in fact the efficient cause of all those phenomena which come within the scope of chemical philosophy, is denoted in general terms, as Chemical Attraction, for which designation, that of Elective Attraction is sometimes substituted, as, owing to the different degrees of intensity in which in each body it manifests itself towards the different substances presented to it, a sort of election or *preference* may be said to be shewn for that for which its attraction is strongest.

The operation of elective attraction is however best displayed in combinations between inorganic bodies, where the two constituents are naturally in an antagonistic state, and differently related to electricity

In such cases, wherever a new compound is produced, one of the ingredients of the preceding combination is separated, by reason of the superior attraction exerted by the new substance presented to it, and it is by taking advantage of this property, that we are enabled to effect the *analysis* of a compound, detaching from each other its elements, and thus obtaining them in a form, in which they are recognisable by their known characters.

The general laws of elective attraction are too

familiar to chemists, to require any particular notice in a book of this description, and, being in themselves sufficiently simple, may be readily learnt from any elementary treatise on chemistry*; but it must be confessed, that the manner and degree in which chemical affinity may be modified or overruled by mechanical or physical influences, is a subject which still requires a fuller and a more profound examination.

Berthollet has long ago pointed out many of these disturbing forces in a work† which deserves to be studied anew by the lights of modern information, and Chevreul, in the chapter he has appended to Pelouze's recently published treatise‡, has communicated some valuable remarks on the same subject.

Berthollet, it is well known, laid much stress upon the influence of the mass in augmenting the force of chemical affinity inherent in a body, and Chevreul justly remarks, that although the movements of the atoms in cases of chemical combination are too minute to be perceived, yet that we must suppose them really to take place, and

* See for instance Fownes' Manual.

† Statique chimique.

‡ Cours de Chimie generale, 1850.

therefore that they will be more considerable in proportion as the number of atoms is greater.

For a force communicating a given velocity to a given mass, will impart only the half of it to one of twice the bulk assumed. Hence it happens, that when we boil together sulphuric acid and water, the heat requires to be increased, in order to enhance the force of elasticity, in proportion as the water evaporates, and the quantity of acid becomes relatively greater.

Berthollet justly remarked, that when two salts are brought together, the new combinations that result will be determined, in some cases by the cohesion, and in others by the volatility of the resulting products; thus sulphate of baryta, from the superior cohesion of its particles, and their consequent insolubility in water, is formed in preference, whenever the two elements of sulphuric acid and baryta are in contact; and thus in like manner the volatility of carbonate of ammonia determines its production, whenever a fixed carbonate is heated along with an ammoniacal compound of a less fugitive description.

But although this may serve for an expression of the fact, Chevreul justly observes, that in attributing the formation of the salt in one instance to its cohesion, and in the other to its volatility,

Berthollet was guilty of the solecism of supposing a substance to *act* before it came into existence; for these properties belong to the salts when formed, and cannot therefore be appealed to as accounting for their formation.

The same remark will of course apply to a new cause influencing chemical affinity, which professor Graham has recently pointed out*, as a corollary upon his interesting researches on the different power possessed by salts of diffusing themselves through water†.

In this latter paper he had shewn, that when two salts are dissolved together in water, the medium by which they are surrounded being also water, they diffuse themselves independently, each salt maintaining its own rate of diffusion.

Hence after a time, a partial separation of the mixed salts will take place, the more diffusible one escaping into the general body of liquid surrounding it, at a more rapid rate than the other ‡.

Now it appears, that there is the same tendency in salts to arrange themselves so as to form the

* Quarterly Journ. of the Chem. Society, No. IX.

† Philosophical Trans. for 1850.

‡ The following woodcut will represent the apparatus by the aid of which the experiments were conducted, where A

most diffusible compounds, as there is in them to form the most cohesive and the most volatile ones.

Accordingly the tendency to diffusion may be taken advantage of in many instances, for the purpose of decomposing certain salts, as for instance, the alkaline sulphates or chlorides by means of lime.

Sulphate of potass for instance, dissolved in water, containing in solution lime, or even carbonate of lime dissolved in carbonic acid, being placed in a phial surrounded by a jar filled with pure water, or with lime-water, is partially decomposed, because both the hydrate, and the carbonate of potass, resulting from its decomposition, are more diffusible salts than itself.

Hence after a time, a large proportion either of hydrate or of carbonate of potass was formed in the jar, and a corresponding diminution of sul-

represents the diffusion phial, and A, B the same phial with the jar of water surrounding it.



phate was ascertained to have taken place in the diffusion phial.

In the case of chloride of potassium or of sodium, salts which are less diffusible than the hydrates of their respective alkalies, little or no effect was produced by a repetition of the above mode of procedure, shewing, that the efficacy of this principle in controlling the operation of chemical affinity has its limits.

When however solutions, of sulphate of lime, and of chloride of sodium, the latter in the proportion of 2 per cent. to the water, were boiled for some time together, and then mixed with an equal volume of lime-water, the chloride of sodium was partially decomposed in the diffusion phial, and hydrate of soda made its appearance in the water of the exterior jar.

Hence it appears, that by heating together sulphate of lime and chloride of sodium dissolved in water, sulphate of soda is formed by the double decomposition of the preexisting salts, and that this sulphate of soda is then decomposed in the diffusion phial, through the greater diffusibility of the hydrate.

It is possible, that what can be effected artificially, takes place also in nature, and that in this manner may be brought about the supply of alka-

line carbonates to plants, through the decomposition, either of alkaline sulphates or chlorides, dissolved in the water that percolates through the earth, by means of lime or its carbonate, aided by the greater diffusibility of the alkalies that result.

“The soluble salts of the soil may be supposed to be carried down together, to a certain depth, by the first portion of rain which falls, while they afterwards find an atmosphere of nearly pure water in the moisture which falls last, and occupies the surface stratum of the soil.

“Diffusion of the salts upwards into this water, with its separations and decompositions, must necessarily ensue, and the salts of potass and ammonia, which are most required for vegetation, possessing the highest diffusibility, will rise first.

“The preeminent diffusibility of the alkaline hydrates may also be called into action in the soil by hydrate of lime, particularly as quick-lime is applied as a top-dressing to grass lands.”

The above remarks may serve to point out a few of those modifying influences, which control the operation of the ordinary laws of elective attraction, propounded to us by the great Authorities of a former age of chemistry.

But something more must be said in correction

of these views, with respect to the particular elements, betwixt which the play of affinities was supposed to take place, in the formation of one important class of compounds, namely, that of salts. X

If we go back to the period of Lavoisier, when the present nomenclature of chemistry was established, it will be found that oxygen was regarded as the pivot upon which almost all chemical changes turned.

It was represented as the universal principle of acidification, the element, by uniting with which, various simple substances are converted into compounds, distinguished—by the energy with which they act upon organic as well as inorganic bodies—by the reddening they occasion in blue vegetable colours—by their power of neutralizing or destroying the properties of alkalies, earths, and metallic oxides—and by forming with them the class of bodies which we designate as salts.

An hypothesis at once so simple and so plausible, was well calculated to command the confidence of the public, or the long-known fact, that sulphuretted hydrogen, a gas which contains no oxygen, nevertheless possesses all the features of an acid, would have itself been sufficient to lead to its abandonment. It was not however until sir Humphry Davy had established by close and

rigorous deductions from experiment, the claims of chlorine, and subsequently of other cognate elements, to be regarded as acidifying principles equally with oxygen itself, that it was perceived, how baseless had been the foundation upon which the whole of this ingenious superstructure depended for support.

Sir Humphry had likewise the sagacity to suggest, although he did not possess the influence to introduce, a theory diametrically opposed to that of Lavoisier, which has of late been looked upon with favour by several of the most eminent of our chemists, and seems not unlikely hereafter to meet with general reception.

Its main position is, that hydrogen, and not oxygen, must be regarded as generally present in acids, and the most convincing argument in its behalf seems to be, that those which are most energetic, such even as the sulphuric, if they do not contain hydrogen, either alone, or in the form of water, exert no chemical reaction whatsoever.

But, in order to afford the means of estimating the claims which this theory puts forth for our support, it will be necessary in the first place for me to present a brief sketch of the beautiful researches made by professor Graham, respecting

the part which water plays in the constitution of many compound bodies.

This, Graham has shewn, is by no means limited to the office hitherto assigned to it, of imparting to the substance with which it had combined a peculiar geometrical form, since, on the contrary, it contributes also in an essential manner to the existence of those chemical properties which characterise it.

The Professor establishes in the first place, that certain acids, such as the phosphoric, combine in definite proportions with water, just as they do with bases—that one atom of water at least is necessary to their independent existence, but that they disengage this atom when they unite to an equivalent quantity of any other base.

Thus water takes the part of an acid with bases, as in the case of hydrate of potass, of lime, &c.; and of a base with acids, as the hydrous sulphuric and nitric acids testify.

We may therefore distinguish several states, in which water exists as one of the constituents of a compound.

The first is that of water of crystallization, namely, the portion regarded essential to the crystalline form which the substance assumes.

The second state in which it appears is that of

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an acid, in which relation it exists, when combined with the alkalis, earths, &c.

The third is that of a base, being in this case essential to the separate existence of the acid with which it is combined, but liable to be displaced by any other base, possessing a more powerful affinity for the acid than it can itself exert.

To these professor Graham has since added a fourth condition in which it may occur, forming what in his Memoir of the year 1837 he has called *constitutional water*.

In the latter case we have a certain proportion of water, united to a given salt, but capable of being driven off from it by another, in consequence of the stronger attraction which the latter possesses.

Thus the sulphates of magnesia, of zinc, &c. contain, besides their water of crystallization, a proportion of constitutional water, which may be replaced by sulphate of potass; so that, instead of $\text{Zn O}, \text{S O}^3 + \text{H O}$ we obtain $\text{Zn O}, \text{S O}^3 + \text{K O}, \text{S O}^3$ K O, S O³ being substituted for H O.

This constitutional water, it may be observed, is expelled with more difficulty than the water of crystallization.

Bisulphate of potass, is a sulphate of potass united to a sulphate of water, and its constitution may be explained as follows :

Sulphuric acid (sp. gr. 1.78) consists of H O , $\text{S O}^3 + \text{H O}$, or of

Acid 1, basic water 1, + constitutional water 1, and the latter is replaced by sulphate of potass; hence we have H O , $\text{S O}^3 + \text{K O}$, S O^3 .

Sulphate of magnesia is Mg O , $\text{S O}^3 + \text{H O}$, or sulphate of magnesia, with 1 atom of constitutional water, omitting the 6 atoms of water of crystallization, and the H O may be replaced by K O , S O^3 (sulphate of potass), forming the salt called sulphate of magnesia and potass.

Oxalic acid contains 1 atom of basic water, and 2 atoms of constitutional water, hence its formula is H O , $\text{C}^2 \text{O}^3 + 2 \text{H O}$. In the oxalic salts of the magnesian family the constitutional water is retained, the basic disengaged. Thus oxalate of magnesia is Mg O , $\text{C}^2 \text{O}^3 + 2 \text{H O}$, the basic water being replaced by magnesia; oxalate of potass K O , $\text{C}^2 \text{O}^3 + \text{H O}$; the binoxalate K O , $\text{C}^2 \text{O}^3 + \text{H O}$, $\text{C}^2 \text{O}^3 + \text{H O}$.

Thus nitric acid is H O , $\text{N O}^5 + 3 \text{H O}$, whilst in nitrate of copper the H O (basic water) is replaced by Cu O .

Professor Graham has also pointed out a curious law, with regard to the acids of phosphorus and of arsenic, which has since been proved to extend to others, I mean, that the acid possesses

an affinity for just so many atoms of a base, as the number of atoms of water with which it is already combined.

Thus common phosphoric acid, having 3 atoms of water, unites with 3 atoms of base; pyrophosphoric, having 2 of water, combines with 2 of base; metaphosphoric, having 1 of water, with 1 of base.

This disposition it may be difficult to account for according to the known laws of chemistry, but Liebig mentions other instances of a similar kind.

Thus Cyanuric acid consists of $\text{Cy}^3 \text{O}^3 + 3 \text{ Aq.}$

Fulminic $\text{Cy}^2 \text{O}^2 + 2 \text{ Aq.}$

Cyanic $\text{C}^1 \text{O}^1 + 1 \text{ Aq.}$

Citric $\text{C}^{12} \text{H}^{10} \text{O}^{11} + 3 \text{ Aq.}$

Pyrocitric $\text{C}^{10} \text{H}^8 \text{O}^6 + 2 \text{ Aq.}$

2nd pyrocitric $\text{C}^5 \text{H}^4 \text{O}^6 + 1 \text{ Aq.}$

The same chemist explains these facts on the following principle:

As dry tartaric acid has no tendency to combine with bases, so the phosphoric only owes its acid properties to the water it contains. Accordingly, if one third of its water be abstracted from it, one third of the acid becomes anhydrous, and consequently inactive; and if two thirds are removed, a corresponding portion of acid will be converted into the same condition of inertness, the remainder alone being capable of uniting with bases.

Hence metaphosphoric and pyrophosphoric only differ, from each other, and from common phosphoric acid, the first in containing 1, the second 2 atoms, of inactive or anhydrous phosphoric acid.

The important part which in these cases water appears to perform, in imparting, to the compound into which it enters as an ingredient, its active properties, has been appealed to, as lending much support to the theory of Davy above alluded to, in which hydrogen is supposed to be the principle displaced, when an union takes place between an acid and a base.

In order to adopt this view, we have only to suppose, the oxygen of the water to be united with the other ingredients of the acid, and its hydrogen to combine with the oxygen of the base which displaces it.

Thus let us take the acids derived from sulphur, the symbol of an atom of which is S.

S	+H	=	Sulphuretted hydrogen
S O ₃	+H	=	Sulphurous acid
S O ₄	+H	=	Sulphuric acid
S ₂ O ₃	+H	=	Hyposulphurous acid
S ₂ O ₆	+H	=	Hyposulphuric acid
S ₂ Cy	+H	=	Sulphocyanic acid
S O ₃ Cl	+H	=	Chlorosulphuric acid
S N O ₅	+H	=	Nitrosulphuric acid.

Here, notwithstanding the difference in com-

position subsisting between these acids in other respects, yet as they possess the same amount of hydrogen, they all neutralize exactly an equal amount of base.

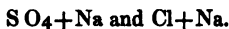
According to this view, when any one of these acids forms a salt, the oxygen of the oxide combines with its hydrogen, and the base assumes its place.

Thus

S H with K O (potass) form S K and H O
 S O₄ H with Fe O (protoxide of iron)— S O₄ Fe, and H O.

The principal recommendation of this theory appears to consist, in bringing under one common head, the salts formed by acids into which oxygen enters, and likewise those, called haloid, of which chlorine and other allied principles constitute a part.

Thus sulphate of soda, an oxygen salt, and chloride of sodium, an haloid one, will be formed on the same principle, namely,



It also carries on the analogy between an acid and a salt, thus :

Cl + H forms muriatic acid,
 Cl + Na — common salt,
 SO₄ + H — sulphuric acid,
 SO₄ + Na — sulphate of soda ;

and so with the rest.

It also serves to explain, why phosphoric acid with 1 atom of water takes up 1 atom of base; with 2 of water 2 of base; and so on; and also the correspondence between the number of atoms of oxygen in a base, and of atoms of acid necessary to combine with it; because each atom of acid contains only 1 atom of hydrogen, which can only combine with the same proportion of oxygen.

It relieves us also from the necessity of attributing the evolution of hydrogen, which takes place through the action of sulphuric acid upon zinc or iron, to what has been called a *predisposing* affinity; a supposition which, as in the cases alluded to in the former part of this chapter, involves the absurdity of imagining a substance to *act*, before it *exists*.

If on the other hand sulphuric acid be composed of a certain number of atoms, of sulphur, of oxygen, and of hydrogen, the metal may be supposed to take the place of the latter element, forming with the acid a new compound, which we commonly denominate sulphate of oxide of zinc, but which may be regarded rather, as a compound of the metal zinc with the acid radical SO_4 .

These, and other arguments in favour of the Binary Theory, as it is called, of acids, are very

clearly and forcibly put forward in Professor Graham's Treatise; but the necessity which it involves, of introducing many new hypothetical radicals, and of substituting for the present established nomenclature, one somewhat uncouth, and to most persons perplexing, has hitherto stood in the way of its general adoption.

It would also have stronger pretensions to favour, if it could be shewn, that hydrogen in one form or other is a constituent of every acid, but this cannot be the case with respect to one extensive class, namely, the sulphur-salts, if the electro-negative element of these compounds be admitted to deserve the name and character of an acid; and the gaseous trifluoride of boron, which contains no hydrogen, unites with ammonia, and forms with it a peculiar salt.

Neither does hydrogen necessarily communicate acid properties, if it be true, as Dr. Wilson* has stated, that dry sulphuretted hydrogen exerts no greater power of reddening litmus, than anhydrous sulphuric acid possesses.

In all the above cases, the elements that combine are necessarily antagonistic; for, whether we adopt the old theory, which supposes an acid to

* Journal of the Chem. Soc. part VIII.

unite with the oxide of a metallic base, or the new one, which interprets the same phenomena, by the supposed substitution of the metal for the hydrogen, which combines with the oxygen of the former, one of the elements of the combination is +, and the other —; as is likewise the hydrogen eliminated, with reference to the oxygen with which it unites.

But in many of the compounds, existing in the two kingdoms of organic matter, or derived from the products of animal or vegetable secretions, this antagonism between the elements of the compounds produced does not prevail, nor is there that powerful affinity in the constituents towards each other, which should enable them to hold together, in spite of changes of temperature and other counteracting influences.

The affinity of one element for another may in these cases be weakened by the opposite attraction of a third, so that those binary combinations, which exist amongst inorganic bodies, often fail to take place.

Thus in them oxygen does not form water with hydrogen, nor carbonic acid with carbon, but the three elements may remain together side by side, in a state of unstable equilibrium, which is maintained, as much perhaps by the inertia of

the atoms, as by the controlling power of chemical affinity.

Now these last mentioned cases more especially may be brought forwards, as illustrating another mode of decomposition, which was first clearly distinguished by Berzelius.

That great chemist pointed out several important differences between it, and the ordinary kind with which chemists were familiar, inasmuch as the latter, being brought about by the superior attraction of a foreign body, necessarily involves the substitution of the latter for the element which had been disengaged.

In the general point of view, in which it was at first contemplated, the effect was by no means considered as confined to organic substances, for many cases taken from the inorganic kingdom had been adduced by the Swedish philosopher above alluded to, for the purpose of shewing, that there were substances, capable of causing decomposition, and of determining new unions between certain elementary, as well as certain compound bodies, merely by virtue of their *presence*, and without themselves combining with either constituent.

This mode of decomposition, being distinct from the ordinary one, he indicated by the term

catalysis, nor can there be any objection to its use, provided we understand it merely as the expression of a *fact*, without imagining, that we are offering it as an explanation of the phenomena which it describes.

The first case probably of the kind, which presented itself to the observation of chemists, was that made known by Professor Dobereiner of Jena, in the property which he shewed to belong to spongy platina, of bringing about an union between hydrogen and oxygen gases, at a temperature at which under common circumstances they remain together without combining, and yet without any change in the condition of the metal itself ensuing.

This remarkable discovery was followed by other similar ones, in which the same substance was the agent employed.

Thus alcohol, when once kindled, will continue, after the flame has been extinguished, to unite with oxygen, rapidly enough to cause, if in contact with spongy platinum, a certain degree of heat, being converted in consequence into acetic acid; and in like manner pyroxylic, or wood-spirit, when left in contact with the same under a covered jar, is converted into formic acid.

Various other substances appear to act catalyti-

cally upon that curious compound, called oxygenized water ; its oxygen being disengaged, and its reconversion into common water being effected, by the alkalies, the metals, or the metallic oxides, when it is brought into contact with them, although in cases where the substance introduced does not combine with the oxygen liberated.

In like manner the nitrosulphuric acid of Pelouze is decomposed, by spongy platinum, by oxide of silver, by metallic silver, by powdered charcoal, and by other substances which are not acted upon by any of the constituents of the compounds which they decompose ; and bisulphuretted hydrogen is likewise decomposed by the action of alkalies, whilst it is rendered more stable by acids.

The above cases are taken from the inorganic kingdom, and although the word *catalysis* may perhaps be admissible with reference to them all, in the guarded sense in which we have defined that term, yet it is quite evident, that they differ widely one from the other, both in the effect produced, and in the exciting cause.

When spongy platinum, for instance, produces combination, it operates apparently by bringing into closer contact the particles of the gases, the force of whose mutual attraction is at the same

time enhanced by the elevation of temperature, favoured by the small capacity for heat belonging to the metal.

The action of the different reagents on oxygenized water, &c., and likewise that of metallic surfaces on ammonia, is on the contrary to produce decomposition, and its probable mode of operation, is through the adhesive affinity subsisting between the gases, and the substances in contact with them.

In compounds derived from the processes of organic life, as well as amongst those actually organized, what is called catalytic action is of still more common occurrence.

Thus the conversion of alcohol into ether, and the production of alcohol itself from vinous fermentation, have both been assigned to this imaginary cause.

But with respect to the nature of etherification, the chemical world is still much divided.

It is generally indeed admitted, that ether ($C_4 H_5 O$) is formed from alcohol ($C_4 H_5 O + HO$) by the abstraction of its water, and hence sulphuric acid, which has a strong affinity for the latter, is the agent usually employed for effecting this change.

But there are two modes of conceiving its operation, the first and most simple being that of regarding it as instrumental, merely by combining with the water, and by thus enabling the ether to distil over *per se*; the latter, that of supposing the acid, first to take the place of the water, substituting for alcohol, or the hydrate of ether, ($C_4 H_5 O + HO$) a compound of $C_4 H_5 O + 2SO^3$, called sulphovinic acid, which at a higher temperature is itself decomposed, the sulphuric acid, being separated from its combination with ether by water, and forming $SO^3 + 2HO$, whilst the ether disengaged distils over.

This latter is Liebig's theory, and it is based on the following fact amongst others—namely, that the acid compound of ether, called sulphovinic acid, is unquestionably formed, when hydrated sulphuric acid is brought into contact with the vapour of ether, as well as by heating together a mixture of hydrated sulphuric acid and alcohol to 212° ; but, that at a temperature exceeding 284° , this same compound is decomposed, into ether which distils over, and into sulphuric acid; which, being anhydrous, will seize on all the water in the vicinity of the ether, and thus prevent the reconversion of the latter into alcohol.

Were the acid not present, the ether would be

entirely reconverted into alcohol, as it unites with water in a gaseous state at the moment of its production, and hence it happens, that a portion of alcohol always comes over along with the ether, in consequence of the combination which takes place between the latter, and the aqueous vapour which floats upon the surface of the liquid.

Thus hydrated sulphuric acid is constantly ready to decompose a fresh portion of alcohol; and thus, by adding the latter in a slow continuous current, by means of an apparatus contrived by Liebig*, the original dose of acid might go on producing for an indefinite time the conversion of alcohol into ether, were it not that the quantity originally present undergoes a gradual diminution, owing to the formation of a compound ether, a neutral sulphate of oxide of ethyle, commonly called oil of wine, which distils over into the receiver along with the ether generated.

Such is a brief sketch of Liebig's theory of etherification, which is supported by numerous facts, and seemed to afford the most satisfactory view of the whole phenomenon, that had been offered.

Recently however, Professor Graham† has re-

* See Fownes' Chemistry, p. 390.

† See Quarterly Journal of the Chemical Society, No. 9.

ported some experiments, which militate against the idea, that the formation of sulphovinic acid is necessary as a preliminary step in the process of etherification.

He has shewn, that a mixture consisting of 1 volume of oil of vitriol and 4 of alcohol, submitted in a sealed tube to a temperature ranging from 284° to 352° of Fahr., is partially converted into ether, no sulphovinic acid being at the same time formed.

He has rendered it probable moreover, that the conversion of alcohol into ether, which we connect with the presence of sulphovinic acid, takes place equally, when any acid salt of sulphuric acid, such as the bisulphate of soda, is introduced; and that the same sulphovinic acid, which is capable, at a temperature of 290° , of converting alcohol into ether, when added to it in a close tube, yields by itself no ether, when mixed with water, under the same circumstances, and at the same temperature.

Hence Professor Graham draws an inference favourable to the views of Mitscherlich, who regarded sulphuric acid, as acting by its *presence* or *contact* upon the alcohol, and breaking it up into ether and water, without itself combining with the resulting product.

This property, which may be regarded as a genuine case of *catalytic action*, if we choose to employ that term, sulphuric acid will share with its several acid salts, of which the so called sulphovinic acid ($C_4H_5O + 2SO_3$) is one, and bisulphate of soda ($NaO + 2SO_3$) may rank as another.

Berzelius likewise contended, that the process of fermentation itself, during which sugar is converted into alcohol and carbonic acid, furnishes a case of catalytic action.

It seems indeed to be fully ascertained, that a small quantity of a substance present in yeast, called gluten, is essential to the process, for pure sugar and water will not ferment by themselves; and no fermentation takes place within the grape itself, because the cells which contain the saccharine and other fermentable matters, are distinct from those including the material which sets on foot the action.

But as this substance, so far from combining with the ingredients, is even increased in quantity during the process, it has been inferred, that it acts upon the saccharine matter *catalytically*.

This however is a mere *expression* of the fact, not an *interpretation* of it; and accordingly,

instead of resting satisfied with the mere statement, that gluten by its presence causes saccharine matter to ferment, we are naturally led to inquire, whether this influence may not be a particular case of some more general law or principle, which remains for us to investigate.

Now the manner in which the change is brought about, in the process of fermentation, has been traced as far back perhaps as the case admits by Baron Liebig, and to the admirable comments made by him upon this class of phenomena, we are indebted for the development of a new principle in chemistry, the adoption of which may serve to enlighten us, with respect to the phenomena, not only of dead, but likewise of living matter, or rather perhaps may assist in bridging over that hitherto impassable gulf, which separates the two kingdoms of animate and inanimate nature.

The most general expression of the law which Liebig has laid down is, *that an atom or molecule, put into action by any power whatsoever, will communicate its own motion to another atom in contact with it.*

Hence it is only necessary to suppose the new substance, however small in quantity, to be in the act of undergoing change, so that its particles

shall be in a state of motion, for a change to be set up in a contiguous body, provided the elements of the latter be in a state of unstable equilibrium.

Hence the tendency to be affected catalytically by the presence of a body undergoing decomposition, will be in some degree proportionate to the complexity of its composition, and accordingly organic substances will be those most subject to this influence.

Thus the presence of a small quantity of ferment will set in motion the particles of a large amount of sugar, and this action, when once commenced, will be continued indefinitely, until the whole mass has undergone change.

The above theory of fermentation has been eloquently set forth by Baron Liebig in several well-known publications*, and has been applied by him most ingeniously to the explanation, of disease in living, as well as of the spontaneous changes that occur in dead matter.

But I must not omit to notice, that a different explanation of the process upon which the theory is principally founded has been offered by a

* Animal Chemistry, Chemical Letters, &c.

French Savant, M. Cagniard de la Tour, and is countenanced by the authority of Mitscherlich, and of other great continental chemists.

M. Cagniard de la Tour maintains, that gluten is a living principle, which consists of a number of little globular bodies capable of reproduction, and that so long as these retain their vitality, they continue to act upon any solution containing sugar, and by some effect of their growth, cause the disengagement of carbonic acid, and the formation of alcohol.

On examining the ferment of beer under the microscope, he found it made up of these little globules, called by him "*Torula cerevisiæ*," and watching it during the continuance of the fermentative process, he perceived new globules appearing, attached to, or emanating from those originally present.

Hence, the organic matter of which yeast consists is regarded by him as capable of growth or of reproduction, and this he considers to be confirmed by the fact, that the material in question, far from being consumed by the process which it sets up, exists on the contrary in larger quantity at its close, than at its commencement.

Liebig, however, whilst admitting that living organisms may obtain a suitable *nidus* in bodies

undergoing fermentation, contends nevertheless, that as in the case of the mites in cheese, their entrance may be prevented by the exclusion of the air which conveys their germs, whilst the globular form of the particles, which has been taken for an evidence of organic structure, he regards as nothing more, than what naturally belongs to substances like gluten and albumen, whose particles have never yet been observed to assume a regular geometrical arrangement.

Adopting then Baron Liebig's explanation, so far as to admit that the presence of a body, whose particles are in a state of motion, does bring about a similar condition in those of another, I will endeavour to apply to its elucidation those principles of electrical induction, which Dr. Faraday has propounded, as a means of accounting for the action of the ordinary voltaic pile.

It is admitted, in the first place, that the elements of most organic compounds are in a state of unstable equilibrium, in some cases indeed with the divellent and quiescent attractions so nearly balanced, that nothing but the inertia of the atoms tends to maintain the existing combination. Any cause, then, which should enhance in the slightest degree the force of affinity sub-

sisting between the atoms not already combined, must bring about a new arrangement of the entire mass.

Now the introduction of the minutest portion of a foreign body, such as a ferment, which is itself undergoing chemical action, may operate in this manner. No chemical action can take place, without rendering the substances between which it operates, *pro tempore*, positive and negative, or, to adopt the explanation of Faraday, causing a polar state in their particles. The polarity of one particle must induce an opposite condition in that nearest to it; the latter affect consecutively the next in order, and so on throughout the entire mass. But the accumulation of attractive energy about a particular pole of a particle, must, of course, alter its relation to that next it, and thus the induced chemical affinities will be propagated throughout the whole mass, until a totally new arrangement of the constituent elements ensues.

This property of stirring up dormant chemical affinities is not confined indeed to ferments, or other foreign matters which may be introduced into organic compounds—it is seen likewise to prevail in various processes in which inorganic matter alone is concerned, and should therefore

be referred to a cause which admits of being extended to both.

Thus platina alone is unable to decompose nitric acid, whilst an alloy of platina and silver is readily dissolved in it.

Thus azote by itself is not combustible, but when mixed with hydrogen, the latter communicates to it the property of burning in atmospheric air, or in oxygen gas.

Thus water acidulated with sulphuric acid is not decomposed by copper, and but slowly under the same circumstances by nickel, but an alloy of these two metals with zinc, called German silver, is speedily dissolved.

If we turn to those processes which are going on in the vegetable kingdom, we shall find abundant instances of what is called catalysis, referable probably in a great degree to the same fermentative action which Liebig has so well explained.

But the organic compound perhaps which from the variety of changes it undergoes, illustrates this mode of action most strikingly, is starch, which passes successively into sugar, gum, and the substance called by the French chemists *dextrine*, under the operation of substances, which do

not enter into union either with it, or with the ultimate principles of which it consists.

Payen in France, who has written a very elaborate Memoir on Starch, in the *Annales des Sciences Naturelles*, represents it as composed of a number of concentric layers, surrounding a common axis, so as to form a globular or elliptical mass.

In its natural condition the whole mass of it is insoluble in cold water, but long continued boiling causes a change in its characters, rendering it gradually soluble in water of ordinary temperature. When this is brought about, it acquires the property of polarizing light to the right, and on account of this peculiarity has acquired the name of *dextrine*.

Now it seems to be ascertained, that the change from insoluble starch into soluble dextrine, which is brought about artificially by boiling, takes place also in nature spontaneously, occurring however in those parts of the plant only, in which it is requisite that the amylaceous matter, stored up for the purposes of its internal economy, should be rendered soluble in water, so as to be dissolved by the aqueous fluid of the sap, and carried up by the vessels or channels of circulation to those parts where a supply of it is wanted.

In both these cases, it is the opinion of Payen, suggested by the experiments of Pelouze and others, that the change is brought about, through the instrumentality of a minute portion of a substance found along with it, in the seeds of barley, oats, and probably of most other plants, *so soon as they begin to germinate*, and which, from its property of separating starch from other ingredients, as well as of altering its properties, is called *diastase*. It may be obtained by macerating malt in cold water, and then submitting it to a strong pressure. The liquid expressed contains the diastase, in union with other matters, separable from it however by the addition of alcohol, which precipitates it in the form of a white flocculent mass.

Thus diastase seems to be expressly intended by nature to render starch soluble, and thereby capable of being taken up by the sap, and it is interesting to find, that it exists in the potatoe, only in the tubers, and there just at the point of insertion of the young shoots, that is, exactly at the spot where they would be sent out; and consequently where it might be of use in rendering the starch soluble.

Thus it may be pointed out as a beautiful arrangement of nature, that this magazine of nou-

rishment should, so long as it is not wanted, be insoluble in cold water, so as to remain unchanged and unacted upon, whilst a provision is made for rendering it soluble, and thereby fitted to circulate through the plant, by preparing, just where it is required, this minute quantity of a foreign matter, which, without affecting its properties by entering into combination with it, serves, nevertheless, so to modify it, as to render it soluble in the sap.

Diastase then seems to act *catalytically* upon starch, producing a change in the arrangement of its particles, and, consequently, metamorphosing it into a new substance, without itself combining with it, either during the process of conversion, or after it.

Another case of so-called catalytic action, dependent on a similar cause, is presented by the conversion of starch into sugar through the agency of sulphuric acid.

If starch be boiled in water containing about $\frac{1}{100}$ th part of sulphuric acid, the liquor in about 24 hours acquires a sweet taste, and the starch disappears.

But that this is not owing to any chemical union between the sulphuric acid and starch, is

evident from the circumstance, that an equal amount of acid exists in the solution, after the production of the sugar, as before.

The exact manner in which this is brought about is still rather obscure, although by Liebig it is regarded as a similar case to the production of ether, a combination like sulphovinic acid being first effected between the acid and the starch, which is afterwards decomposed by boiling into sugar and acid, although even on this supposition, the production of sugar must be owing to some new arrangement of the elements of the starch.

The weight however due to this suggestion cannot be fairly estimated, until we have considered the further question, how far the principle of life itself is capable of explaining the phenomena of organization, and this accordingly will form the subject of the succeeding chapter.

CHAPTER XI.

Influence of chemical attraction upon living matter—how far capable of explaining the permanency of organic principles during life—by what agency the proximate principles of living matter were originally produced—Hunter's and Abernethy's opinion on this subject commented on—Some organic principles produced by chemical means—broad distinction in nature between those which *have*, and those which *have not* been produced by art—The proximate principles of animals generally elaborated by plants—exceptions to this—Whether albumen can be formed by the powers of animal life—Difficulties in the way of such a supposition—Conclusion, that we are not yet justified in assuming, that the affinities which operate on living, are essentially different from those which exist in inert matter.

In the preceding chapter it was shewn, that chemical affinity operates upon matter generally, and that if its mode of action be somewhat distinct, when exerted upon organic compounds, from that which

is observed in the combinations that take place amongst inorganic substances, this difference may be resolved into the greater complexity of constitution which usually appertains to the former.

Indeed, although the distinction between organic and inorganic substances be convenient in practice, it is one not easy to be maintained in theory, since no decided line of demarcation has been set up between the one and the other—as for instance, between a substance like alcohol, proceeding from the fermentation of sugar, and carburetted hydrogen, derived from the decomposition of wood and coal—or between the products of saccharine fermentation, and the saccharine material itself which undergoes this process, although the latter be secreted by certain processes carried on within the cells of the plant, the former is wholly independent of organization.

It is true, that the products of organic life are generally more liable to decomposition than other chemical compounds, so that it has been concluded, that their permanence in the living body must be ascribed to the sustaining influence of life, and consequently to what has been called *vital affinity*—a force, which is supposed to come in aid of common chemical attraction, and to render the union between the particles of a body more stable.

That this effect does arise indirectly from the vital functions carried on in the plant or animal, I am far from intending to deny; but in this instance, at least, there seems to be no necessity for invoking the aid of the vital principle, as there is nothing which ordinary chemical forces may not sufficiently explain.

In the first place, it by no means follows that a body, because it is complex in structure, should be liable to spontaneous decomposition. Many indeed, such as paraffine ($C_{48}H_{50}$), naphthaline ($C_{20}H_{8}$), &c., possess a considerable degree of stability, and even those which appear more susceptible of alteration, such as sugar, albumen, and the like, owe their liability to change to the presence of a ferment, and not to the absence of chemical affinity between their particles.

Now the immunity from such changes, which is maintained in an healthy animal body, may arise, not from any superinduced force of attraction derived from the vital principle itself, but from the constant movement to which the animal fluids are subjected, by which *effete* matter is instantly eliminated, and the tendency to decomposition restrained within proper limits.

Those who adopt the opposite view, and regard the elements of an animal or vegetable principle

as held together during life by the superadded influence of vital affinity, seem bound to explain, why the decomposition of the organic structure should not commence immediately upon the cessation of life, instead of being suspended, sometimes for an indefinite period, when those circumstances are absent, by which the action of external forces upon the inanimate body is induced.

The inertia of the atoms is the cause assigned for this permanence, but I can hardly reconcile myself to the idea, that this should be the sole reason, nor indeed do I perceive any such decided line of demarcation between an organic substance like sugar, and an organized one such as fibrine or albumen, as, according to this hypothesis, ought to exist. Both are liable to decomposition when a ferment is present, both resist it for an indefinite period, when preserved free from any such cause of decay. Sugar, no one can doubt, has its particles held together by a powerful chemical affinity; there seems therefore no good reason to deny, that fibrine and albumen are also sometimes maintained after death in their integrity by a weaker description of the same force, and if after death, why not, it may asked, also during the continuance of life?

But admitting that the different organic com-

pounds, which enter into the constitution of the animate body, may be maintained during life in their integrity, without the direct agency of a vital principle, it yet remains to be considered, whether their original production does not require some such assumption.

Do we not indeed find, both amongst vegetables and animals, a numerous class of compounds, which no skill of art, and no play of affinities, unconnected with the influence of vitality, has ever been competent to bring about?

Is it not more philosophical to ascribe to a new and independent cause a set of phenomena, which have never yet been observed to emanate from the unassisted energies of brute matter?

Considerations of this kind persuaded many physiologists of the last century to maintain the doctrine of a Vital Principle, not merely animating and pervading the organized structure, but controlling and influencing its chemical affinities; for besides regarding it as the source of motion, irritability, and the like, they even set it down as the bond of union between the particles of bodies, as the cause of a new species of attraction, which vanished when the organized structure returned to the category of insentient matter.

The celebrated John Hunter, at the close of

the last century, contributed the weight of his authority to this hypothesis, but his remarks on the subject, whether from the obscurity of the question itself, or from his own confused and entangled phraseology, convey to the mind no very definite notion of his meaning.

To his commentator and eulogist, therefore, Mr. Abernethy, I must refer for an exposition of what is called *Mr. Hunter's Theory of Life*, regretting, however, that this celebrated surgeon, whose raciness of manner, and graphic power of depicting his thoughts, imparted an interest to his oral discourses, which will never be effaced from my memory, should, in his zeal to give a wider extension to the views of his master on a subject of pure science, have thought proper to mix up with it considerations of Metaphysics bordering upon the delicate ground of Theology.

It would be easy, I conceive, to turn the tables upon those, who flatter themselves that they are making head against materialism, by seeking to identify the cause of the phenomena of animal and vegetable secretion with the mainspring of life, and to shew, that persons, who, in imitation of Hunter or his disciple Abernethy, would assign to that immaterial principle of our nature, which manifests itself in the operations of thought and

intellect, any concern in the functions of the perishable body, more direct and immediate, than that which it may exert through the instrumentality of the nervous system, so far from establishing on a surer foundation the doctrine of the soul's immortality, are, in fact, degrading this *divinæ particula auræ* to a level with electricity, chemical affinity, and other influences, which equally affect inanimate, as they do animate matter.

But, abandoning the high ground of *à priori* reasoning, let us confine ourselves to the humbler task of considering, whether the facts at present known justify us in assigning to organized matter the power of effecting those chemical changes, which brute matter is incompetent to bring about; and, secondly, if this be the case, whether the efficient cause must be regarded as identical with, or emanating from, that principle of life, which distinguishes it from the latter.

Now with regard to the first of these questions, the discoveries of the last twenty years have brought to light facts, which at first sight would seem to establish an identity, between the forces which operate upon animate and inanimate matter.

The necessity of having recourse to the action of a living principle, suspending the ordinary

affinities of matter, and substituting new ones, can at least be maintained no longer, on the ground of the impossibility of producing by artificial means any of the compounds which result from the processes of vitality, since several bodies of animal or vegetable origin have lately been formed by art without any such interference.

Thus the chemist prepares the acid secretion which was originally obtained from ants, by digesting sugar, starch, or gum, with diluted sulphuric acid.

The same materials, treated with nitric acid, supply him with the oxalic acid, originally derived from the plant whose name it bears.

By artificial means also Wohler succeeded in producing urea, the essential constituent of the urine in all mammiferous animals; and he even obtained a substance identical with the allantoic fluid of the cow, by heating uric acid with peroxide of lead.

In like manner wax may be converted by art into the stearic acid ordinarily contained in the fat of sheep; and again, the stearic acid by further treatment may be metamorphosed into the margaric, which is a constituent in the adipose matter of man*.

* Gerhardt explains this by the absorption of 1 atom of

By other artificial processes, the acid present in amber may be procured from wax, spermaceti, and animal oils of all descriptions; sugar may be obtained from starch, lignine, &c.; benzoic acid from the essential oil of bitter almonds; and the valerianic by heating fusel oil with potass.

But, although a superficial observer might infer from these facts the possibility of elaborating eventually by ordinary chemical methods all the products of vegetable or animal secretion, upon further inquiry it will be found, that the bodies he has succeeded in forming possess a common character, and one which demonstrates, that the line of proceeding by which they are obtained, is exactly the reverse of that which takes place in the ordinary processes of vegetation.

Thus, in the manufacture of the formic, and oxalic, and, if we believe Gerhardt, in that of the margaric acid also, as likewise in the artificial production of urea, we operate, by removing carbon and hydrogen through the instrumentality of sub-

oxygen, when wax is converted into stearic acid, and by the abstraction of $C_2 H_2$ from the latter, when margaric acid is the product obtained. But Brodie's late experiments shew that his numbers are not to be relied upon, although the general principle perhaps may be such as he represents.

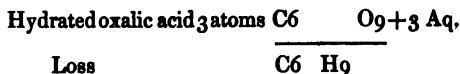
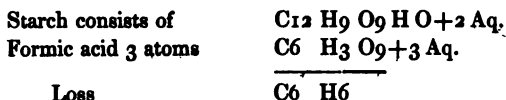
stances which yield oxygen, such as the nitric acid, the oxide of manganese, &c.*

The process therefore is analogous to combustion, carbonic acid being formed, by the removal of carbon from the material acted upon; as likewise water, at the expense of its hydrogen; and ammonia, by the loss of its nitrogen.

Now this is quite the reverse of what takes place in the processes of vegetation, where carbon, hydrogen, and nitrogen are assimilated, in consequence of the decomposition of carbonic acid, water, and ammonia, within the system of the plant.

The first in short is a process of combustion; the second, one of reduction.

* Thus



Urea also is produced under certain circumstances by the oxidation of cyanogen, ammonia being present, cyanogen $C_2 N$ being transformed into cyanic acid, $C_2 N O$, which with ammonia constitutes urea, $C_2 H_4 N_2 O_2 = C_2 N O + N H_3 + H O$.

But chemistry has not yet shewn, that she possesses the means of imitating nature, by forming again starch out of formic acid, or sugar out of the oxalic, through the addition of carbon; so that, except in a few instances, which admit perhaps of being explained, so as to be brought into harmony with the rest, art is only found capable of simplifying organic combinations, not of rendering them more complex.

We may in fact regard the proximate principles of organic beings* as constituting a vast scale of products, at the summit of which may be placed cerebral matter, albumen, fibrine, and other equally complex materials; whilst at the other extremity are met with, carbonic acid, water, and ammonia, having immediately above them wood-spirit, formic acid, and its derivatives.

By burning a portion of their carbon and hydrogen through the operation of re-agents, the chemist may be able to *degrade* an organic compound from an higher to a lower step in the scale, but nature alone seems able to *ascend the ladder*, and by the addition of carbon and hy-

* See Additional Notes, where Gerhardt's Classification of Bodies (*Précis de Chimie Organique*) is alluded to.

drogen, to impart to the first simple combinations, that more complex constitution which belongs to the component parts of an animal fabric.

The Greek philosopher Heraclitus may be quoted as expressing the same idea, when he maintained,

Τὴν μεταβολὴν καλεῖσθαι ὁδὸν ἄνω καὶ κάτω,
 imagining that the world was produced by the gradual fixation or condensation of the rarer elements, and would be ultimately destroyed by a return to their original rarified condition—an idea, which has been expanded by a celebrated French chemist, in his beautiful illustration of the contrast between the two kingdoms of organic nature, the one as an agent of demolishing, the other of reconstructing, the fabric of living matter*.

After all therefore that has yet been done, we are still far from imitating nature in those processes, by which she continues to bring about the

* See Dumas, *Statique Chimique*. The following is the passage in which he sums up his remarks :

“Ainsi tout ce que l’air donne aux plantes, les plantes le cèdent aux animaux, les animaux le rendent à l’air ; cercle éternel dans lequel la vie s’agite et se manifeste, mais où la matière ne fait que changer de place.

“La matière brute de l’air, organisée peu-à-peu dans les plantes, vient donc fonctionner sans changement dans les animaux et servir d’instrument à la pensée ; puis vaincue par cet effort et comme brisée, elle retourne matière brute au grand réservoir d’où elle était sortie.”

wonderful products of organic life, and must admit, that judging from what is as yet known, there would seem to be a power residing in living matter, which is distinct, at least in its effects, from ordinary chemical, and physical forces.

But if it be asked, whether this occult power is to be directly ascribed to the Living Principle, we pause for further information.

Contrary to what might be expected, this Agent, whatsoever it may be, most distinctly manifests its presence where the vital principle is weakest, so that it may even be doubted, whether animals in any degree partake of it.

The beautiful researches of Liebig, Mulder, and Dumas have indeed shewn, that the vegetable world is the Laboratory, in which are prepared all the most important of those proximate principles which together form the fabric of the animal; they have proved, that the materials both for nourishing the frame, and for maintaining its temperature, are prepared by plants, and received by them into the system with little or no modification, so that the Living Principle in animals is, under ordinary circumstances at least, utterly incompetent to produce any of those compounds that enter into their organization.

The only animal matters, in the formation of which the healthy functions of animals appear to have a share, are fat, gelatine, and, according to Dr. Alison, albumen, the latter, however, under extraordinary circumstances alone. In certain states of disease, a peculiar compound, called by Mulder the tritoxide of proteine, makes its appearance, and it is possible that there may be a few other such products.

The generation of fat from sugar is maintained by Liebig, but denied by Boussingault and Dumas; admitting the fact, however, on the authority of the former chemist, it amounts merely to the removal of a certain number of atoms of oxygen, and does not imply the addition of any new ingredient to the elements of the sugar*.

* Starch and fat appear to contain the same relative proportions of carbon and hydrogen, but whilst the former possesses 10 atoms of oxygen, the latter has only 1.

If this should strike the reader as militating against what I have stated above, as to the tendency of chemical processes to increase the amount of oxygen, rather than to remove it, he may be reminded, that, according to Liebig, whose remarks on this subject are well worthy of his study (see his *Animal Chemistry* translated by Gregory, p. 80 et seq.), the formation of fat is owing to a transference of a part of the oxygen present in the starch or sugar, to carbon not already assimilated, by which means carbonic acid is given off, and animal heat maintained. The process therefore would after all be one of combustion.

The formation of gelatine* from albumen seems likewise to depend upon the abstraction of a certain amount of carbon and of hydrogen through the oxygen of the air; but the opposite process, by which fibrine might be produced out of gelatine, seems to lie beyond the reach of the vital powers, since the latter substance *per se* is entirely inadequate to maintain life.

The production of tritoxide of proteine from inflamed tissues seems to be due to nothing more than the oxidation of the animal matter, and therefore implies no real exertion of vital energy.

But unquestionably the power of producing albumen, which Dr. Alison ascribes to the animal system under certain circumstances, would indicate a much greater control over the affinities of inert matter, than any of the secretions before-mentioned, involving, as it does, the fixation of

		Carbon	Nitrogen	Hydrogen	Oxygen
Gelatine	{ According to Liebig	108	18	84	40
	{ ————— Mulder	117	18	90	45
Albumen	.....	144	18	108	42

Thus albumen would contain, 2 per cent more oxygen, according to Liebig's estimate, or 3 per cent less, according to Mulder's, than gelatine, but from 16 to 24 more of hydrogen, and from 27 to 36 more of carbon; the nitrogen remaining a constant quantity.

nitrogen, an element, which even the most powerful chemical attractions can only arrest, when in what is called a *nascent state*.

It might seem presumptuous in me to enter the lists with so distinguished a physiologist on a subject to which he has devoted much attention; but it may at least not be improper to point out, that whatever ultimately may be the fate of this proposition, the proofs of it, which Dr. Alison has at present submitted to us, appear to be all of an indirect character, not being founded upon any exact comparison, between the amount of albuminous matter taken into the system from without, and that which had undergone the process of assimilation afterwards.

Much stress indeed is laid upon the increase in the muscular parts of the body, which is observed to take place under the invigorating influence of pure air and exercise, even without any corresponding augmentation in the quantity of food consumed, and likewise on the deficiency in the albuminous constituents of the blood which occurs in scrofula, where the energies of the system are impaired.

But unless it can be distinctly proved, that the quantity of albumen taken into the system is less, than what is actually added to the muscular fibre and the blood within a given time, it may be

always suggested, that the difference between the nutritious effect of the same diet, in health, and in disease, is owing to the more perfect assimilation of that which had been supplied from without, under the former circumstances, than under the latter.

Whatever difficulties there may be attending such a supposition, they appear to me less formidable, than those in which we should be involved, if, whilst recognising in the vegetable kingdom a most elaborate system of contrivances, framed with an evident view to the formation of these very materials for the nutriment of animals, we nevertheless imagine, that the latter are capable through their own efforts of dispensing with any such supply.

The same remark, indeed, seems to apply to the *proximate*, as to the *ultimate* principles which enter into the constitution of animals.

A profound chemist* some years ago suggested the startling proposition, that phosphorus might occasionally be generated, under the influence of extraordinary circumstances, by the processes of animal life.

His belief in the possibility of this arose, from

* See Dr. Prout's Paper, on the changes which take place in the fixed principles of the egg during incubation, *Phil. Tr.* 1822; and also his *Bridgewater Treatise*, 1st edition.

some observations he had made, on the presence of the principle in question in the yolk of the egg, under conditions, that appeared to him to preclude the idea of its being derived from without.

Nevertheless, the inference has never, I believe, been adopted, even by the most ardent admirers of the acuteness and penetration of this original thinker, not from any distrust of his facts, but from the insuperable difficulty they experienced in imagining, that an animal should have the power of producing *that*, which nature has taken so much pains of providing for it by a series of complicated contrivances, the necessity for which seemed established, by the general dependence of animal life upon a due supply of the ingredients they were intended to minister.

An argument of this kind appears too cogent, to be set aside by a few isolated facts, however inexplicable they may at the time appear.

May not the same line of argument be extended to the case before us?

The formation of albumen, indeed, does not *appear* so incredible as the generation of *phosphorus* would be; but Nature, which does nothing in vain, would hardly have provided from without a supply of an ingredient, which the unassisted powers of the animal was able to produce within

376 *Whether vital affinity operates in producing*

itself; and although fat, gelatine, and tritoxide of proteine may be formed within the system, yet it must be recollected, that the two former products can be referred to a process of mere combustion, and the latter to the ordinary chemical one of oxidation; whereas the production of albumen from sugar would imply the fixation of azote, which no vital affinity has ever yet been found competent to bring about.

Upon the whole then, I am more inclined to coincide in the views of Liebig and Dumas upon this subject, in attributing to the functions of the vegetable organization alone, the power of elaborating the proximate principles of organic life, and in limiting those of the animal fabric, except in the few unimportant particulars already noticed, to the one office of maintaining them in their integrity, in spite of the destructive operation of external agents.

Thus far we appear to have advanced on solid ground, but those who are ambitious to push their inquiries further, and to determine in what precise manner these wonderful products are brought about in one of the kingdoms of organic nature, and preserved from destruction in the other, may appeal to the doctrine of vital affin-

ity, as affording them an easy and plausible solution.

It is one, however, in which, notwithstanding the deservedly high authorities that may be quoted in its behalf, I shall be loath to acquiesce*, until the subject of cell-development in plants, the laws of endosmose, and other points which belong peculiarly to organic substances, have been more fully investigated, as even the imperfect acquaintance which we at present possess of the minute structure, whether of plants or of animals, is sufficient to convince us, that Nature has at her disposal an apparatus, of a more refined and subtle description than any which we can command, and therefore that she may be expected to accomplish effects, even by purely chemical and physical agencies, which will perhaps lie ever beyond the reach of the coarser manipulations of Art.

At any rate, I fear it will be difficult to evade

* Humboldt, in his *Allegory of the Rhodian Genius*, published first in 1795, and in the *Latin Aphorisms* appended to his *Subterranean Flora* in 1793, developed the idea of a vital affinity controlling chemical attraction; but in his comments upon this Myth, contained in the new edition of his *Aspects of Nature*, 1849, he declares, that "reflection and continued study, in the domains of physiology and chemistry, have deeply shaken his earlier belief in a peculiar so called vital force."

the force of the remarks, with which a distinguished Writer*, now deceased, concluded his Memoir "on the Theory of Secretion in Animals," even before the new discoveries in chemistry had shewn, how limited the power of animal life, in its most perfect condition, in producing new combinations, must on any hypothesis be allowed to be, namely, "that when we suppose, that any real explanation is afforded of the phenomena, by ascribing them to the operation of the vital principle, or to any vital affinities, which is merely a less simple mode of expressing the fact, we are indulging in one of those delusive attempts to substitute words for ideas, which have so much tended to retard the progress of physiological science."

Let me not however be understood to suppose, that vital actions are the mere result of organization, the direct consequences of that peculiar arrangement of the parts in which they are found to take place.

Organization would indeed seem to be the *result* of vitality, rather than its *causes*—a con-

* See Bostock's Physiology, and for a more lengthened discussion of the subject, Dr. Carpenter's General Physiology.

sequence of the movements impressed upon brute matter by the principle of life, rather than the source of independent movement itself.

But it does not therefore follow, that because we attribute *contractility* to the existence of a principle of life in certain kinds of matter, the chemical processes by which various organized principles are elaborated should arise from the same cause.

It is possible, indeed, as I have already admitted, that such may eventually prove to be the case, but it is also possible, that the peculiar structure of parts, arising out of the movements induced by a vital principle, will be found competent to bring about these phenomena, and it is at least evident, that we are bound to investigate to the full the extent to which such physical causes can be supposed to operate, before pronouncing, whether there may not after all be some *residual phenomenon*, which, as being inexplicable on common principles of science, we shall be driven, as a last resource, to refer to what is rather vaguely denoted by the term of *vital affinity*.

CHAPTER XII.

Uses of the atomic theory in correcting the errors of experiment, and superseding the necessity of so constant an appeal to it—Also from its applicability to cases in which chemical analysis would not be available—as in ascertaining the proportions of bromine and chlorine in a substance found to contain both—Abuse to be guarded against in taking it as our guide—Application of the atomic theory to mineralogy—Minerals shewn by Berzelius to be definite compounds of an acid, or electro-negative, with a base, or electro-positive body, silica belonging to the former class—Rammelsberg's classification of silicious minerals founded upon this principle—Utility of this view shewn from its application to volcanic geology—Definite proportions prevail in the products of the vegetable and animal kingdoms—an analogous law may also be inferred to hold good in the structure of plants, from the numerical proportion observed in their floral organs, &c.,—a similar one even may be traced throughout the system of the universe, in the distances of the planets from the sun, and of the satellites from their respective primaries.

IN this advanced stage of the inquiry, some few of the many important applications of which

the doctrine of definite proportions admits, may perhaps be advantageously pointed out.

It would indeed be superfluous to enlarge upon the proofs already afforded, with respect to the greater precision it has introduced into the science,—the wonderful saving of time and labour which is derived from it, not only by the philosopher in his more speculative inquiries, but even by the manufacturing chemist, in the every day operations of his trade.

It is evident, that no sooner have we ascertained the exact proportion, in which a new substance unites with any one of those bodies whose atomic weight is already determined, than we are enabled by it to calculate in what quantities it must combine with all the remainder, so that, instead of being compelled, as heretofore would have appeared necessary, to analyze every existing combination, in order to determine the proportion of its ingredients, we might rest contented, were it not for the sake of obviating the chances of error in any single experiment, with ascertaining the composition of one out of the whole number of compounds, into which the ingredient in question enters.

Thus for example, knowing already the combining quantities of the several alkalies and

earths, nothing more would be required for ascertaining the composition of all the sulphates, than to determine what proportion the acid might bear to the base in any single salt, and the number of atoms of acid present, its proportion to the remainder being thence deducible by the common rules of arithmetical proportion, or by the use of the mechanical contrivance of the sliding rule.

It is in this way, that within the few years that the atomic theory has been recognised, chemists have laid down the composition of so vast a variety of substances, that, had not the proportion of their ingredients been determinable by the simple law already explained, it might have required ages of laborious experimental research to have completed their analysis.

But the atomic theory is not only useful, by saving the necessity of so frequent an appeal to experiment, as well as by correcting its inaccuracies, but is also available in cases, where the latter would in no degree serve our purpose.

It sometimes happens, that two bodies agree so nearly with respect to the range of their affinities, and the nature of the compounds resulting from their union with the same elements, that we find it exceedingly difficult to

separate them by chemical means one from the other.

This agreement in the details holds good, as might be expected, most remarkably between bodies, which, resembling each other most nearly in their primary properties, are thrown together into the same class, such substances bearing to each other a relation, similar to that of two nearly allied families of plants or animals, the members of which can only be distinguished by an attentive examination of the degree in which their several characteristic properties are developed, or by some secondary difference, which appears to flow but remotely from their leading characteristics.

Thus the fixed alkalies form, with the several acids, salts, which, though differing in point of solubility one from the other, are yet for the most part not so contrasted in that respect, as to afford us a ready means of separating them.

The same holds good with respect to several of the earths, and still more strikingly with the compounds of chlorine and bromine.

The latter substances, indeed, I found myself unable, by any expedient I could devise, to separate completely one from the other*; neither

* See my Memoir on the occurrence of iodine and

could I find, by referring to the original researches of Balard, or the subsequent investigations of Berzelius, relating to the latter principle, that either of these distinguished chemists pretended to have been more successful*.

It occurred to me, however, that an indirect method of calculating the proportions, in which these two elements exist in a compound ascertained to contain both, might be furnished by a knowledge of their respective atomic weights, if we adopted a formula, similar to that pointed out

bromine in certain English mineral waters, Phil. Trans. 1836.

* Even in 1843, twelve years afterwards, I found Professor Rose admitting the same fact, and suggesting in consequence a plan of analysis based upon the same principle as that stated in the text. See French translation, vol. ii. p. 494. His method was to ascertain the weight of the precipitate formed by adding nitrate of silver, to pass dry chlorine through weighed portions of this whilst hot, and to ascertain the loss of weight caused in it through the displacement of the bromine by the chlorine. The difference between the original weight and that belonging to it after this treatment, is to be multiplied by 1.826, in order to determine the quantity of bromine which the gaseous chlorine had driven off. Several other methods indeed are given, but all founded on the same principle, except perhaps one, in which advantage is taken of the solubility of bromide of barium in pure alcohol, as a means of separating it from chloride of barium, which is insoluble in the same menstruum.

several years ago by Gay-Lussac, as applicable to the case of mixed salts consisting partly of soda and partly of potass, combined with the same acid.

Let us suppose, that we have obtained from a given quantity of the substance under examination 100 grains of a salt, consisting of sulphuric acid, with unknown proportions of soda and potass, but with no other ingredient.

Let us set down the quantity of acid at 50 grains, from which it will follow, that the weight of the two bases will together make up the remaining moiety.

Now had the whole of this latter consisted of soda, the quantity of acid should have been only 40 grains, because the atomic weight of sulphuric acid is 40, whilst that of soda is 32, and

$$\text{as } 40 : 32 :: 50 : 40$$

On the contrary, if the whole had been potass, then, as the atomic weight of this latter is 48, the amount required to neutralize the acid would have been 60 grains ; for

$$\text{as } 40 : 48 :: 50 : 60$$

But if we suppose half the acid to be combined with the one alkali, and half with the other, then, and only then, will the weight of the salt corre-

386 *Example of the mode of calculating*

spond exactly with that obtained in the experiments before us ; for

as 40 : 48 :: 25 : 30, and

as 40 : 32 :: 25 : 20

$$\begin{array}{r} \hline 50 + 50 = 100 \end{array}$$

It is easy to apply this to the case of salts containing bromine together with chlorine, assuming that we are sufficiently acquainted with the respective atomic weights of both these principles.

The bromide and chloride of sodium are alike precipitated by nitrate of silver, in the form of an insoluble chloride and bromide of that metal.

Now the atomic weight

of silver is stated to be 110

of chlorine..... 36

of bromine..... 78.4

Suppose therefore we have found the precipitate to weigh 151 grains ; and that, of these, 100 grains have been ascertained by other experiments to consist of silver : then

as 110 : 78.4 :: 50 : 35, and

as 110 : 36 :: 50 : 16

$$\begin{array}{r} \hline 100 + 51 = 151 \end{array}$$

CH. XI. *the proportions of bromine and chlorine.* 387

If therefore half the silver were combined with bromine, and the other half with chlorine, the compound produced would amount to exactly 151 grains, which is found to correspond with the quantity actually obtained.

The following table will shew the quantity of precipitate that may be expected to result from the addition of nitrate of silver to 100 grains of a salt of sodium according to the proportion of chloride and of bromide present.

Quant. of salt.	Quant. of precipit.	Quant. of salt.	Quant. of precipit.	Amount of precip. from the two salts.
100 br. sod. = 184.5	br. silv.	0 ch. sod. = 0	ch. silv.	184.0
90 —	166.0	10 —	24.3	190.3
80 —	148.0	20 —	48.3	196.3
70 —	129.5	30 —	73.0	202.0
60 —	111.0	40 —	95.5	208.5
50 —	92.5	50 —	121.5	214.0
40 —	74.0	60 —	146.0	220.0
30 —	56.0	70 —	170.0	226.0
20 —	37.0	80 —	195.0	232.0
10 —	18.5	90 —	219.0	237.5
0 —	00.0	100 —	243.0	243.0

The following algebraical formula has been proposed for determining the problem in question on the above data, and an example is given of its use in determining the proportions of soda and potass present in a mixture of the two alkalies.

Let W = the number of grains of the mixed salt operated upon,

a = the grain measures of the test which W grains of (p) would require,

b = the grain measures of the test which W grains of (q) would require,

c = the grain measures of the test which W grains of the mixture operated on *have required*.

Suppose x = grains of (p) contained in W grains of the mixture,

$W - x$ = grains of (q) ditto, ditto,

$$\text{Then } \frac{W.p}{W.q} = \frac{a}{b} = \frac{p}{q}$$

$$\text{And } \frac{x.p + (W-x).q}{W.p} = \frac{c}{a}$$

$$\therefore x + (W-x)\frac{q}{p} = W.\frac{c}{a}$$

$$\therefore \left[x - x\frac{b}{a} \right] = W.\left\{ \frac{c}{a} - \frac{b}{a} \right\}$$

$$x \left(\frac{a-b}{a} \right) = W.\left(\frac{c-b}{a} \right)$$

$$x = W.\left(\frac{c-b}{a-b} \right) = \text{grains of } p.$$

$$W - x = W.\left(\frac{a-c}{a-b} \right) = \text{grains of } q.$$

Say that 200 grain measures of the test are

equivalent to 10 grains of muriate of soda, then 10 grains of muriate of potash would require 157.9 grain measures (nearly) of the same test.

Suppose that we have 178.95 grain measures exhausted in one experiment in 10 grains of a mixture of the two salts,

Then

$$x = W \cdot \frac{c-b}{a-b} = 10 \times \frac{178.95 - 157.9}{200 - 157.9} = 10 \times \frac{21.05}{42.1} \\ = 5 \text{ grains of muriate of soda,}$$

And

$$W - x = W \cdot \frac{a-c}{a-b} = 10 \times \frac{200 - 178.95}{200 - 157.9} = 10 \times \frac{21.05}{42.1} \\ = 5 \text{ grains of muriate of potash.}$$

Journal of Science, vol. xx. p. 394.

But whilst pointing out the facilities afforded by the law of definite proportions towards the determination of the quantities of two substances not easily separable which are found together, let me at the same time notice an abuse likely to spring from its adoption, which was adverted to some years ago by Dr. Prout in his *Gulstonian Lectures*.

He there remarks, that "in order to meet the imaginary standards of this bed of Procrustes, real results have been, he fears, too often extended

and compressed beyond all legitimate bounds, and thus truth sacrificed to error."

I fully concur with my late distinguished friend in these observations, although I do not see that the atomic theory of Dalton holds out any stronger temptation to such an abuse, than the law of definite proportions, which alone he was disposed to recognise; for a chemist who adopted the latter, would, if engaged in an analysis which brought out results irreconcilable with any one of these proportions, possess exactly the same motive for adjusting them to the proper standard by this Procrustean process, as he could derive from being an entire convert to the theory of Dalton.

This species of dishonesty, indeed, is by no means peculiarly the besetting sin of chemists—it is incident to the votaries of all those sciences, whose principles are sufficiently fixed to enable them in any degree to predict results, and accordingly it has been expressly laid to the charge of astronomers by Mr. Babbage, in his facetious remarks on the operations of *trimming* and *cooking* observations, introduced into his Essay "On the Decline of Science in England."

No one however would on that account feel inclined to deprecate the establishment of those mathematical laws, which alone render such a

process possible, or be willing to substitute the infancy of a science for its maturity, in order to hold out less opportunity for the commission of frauds of this description.

The Atomic Theory has also supplied the foundation for a natural arrangement of minerals, on the principle of their chemical composition—a point, which ought doubtless to stand foremost in the scale of importance, with reference to a study such as mineralogy, which is indebted to chemistry so mainly, both for its interest and for its advancement.

In order to appreciate the assistance, in this mode of classification, that has been derived from the doctrine of definite proportions, it may be sufficient to glance over the tables of the composition of mineral bodies, appended to an useful little tract of the late Mr. Allan's, entitled, *Mineralogical Synonymes*, the second edition of which was, I believe, published about the very time we were presented with a translation of the work of Berzelius, in which, by means of the clue which the recent discovery of Dalton had afforded him, he attempted to elicit something like order out of this apparent chaos.

At first sight indeed nothing could have seemed

more desperate, than the attempt to account, on any fixed and definite principles, for the combinations between one body and another, which these and other tables of the kind exhibited; in which the ingredients themselves, not only seemed to be present in every imaginable quantity, but were linked together, without the intervention of any substance, for which they were then known to exert an affinity; so that, strange as it would be to suppose, that bodies obeyed different laws, when brought together in the great laboratory of nature, from those which influenced them in our artificial processes, still, the idea of extending to crystallized minerals in general the same inferences, which were admitted with regard to ordinary chemical products, was, for many years after the introduction of the Atomic Theory, ridiculed as absurd and impracticable.

But the difficulties, that stood in the way of such an undertaking, were in a great degree removed, by the happy idea of considering the silica, so commonly present in minerals, as acting the part of an acid, and consequently as being combined with the other earths, and with the alkaline and metallic oxides, in definite proportions.

It is no wonder that this innovation was at first resisted; for it could not but give a shock to all

our preconceived notions, to extend this generic term to a substance like flint, so remarkably deficient in those sensible properties, the possession of which first led us to apply the name of acid, to such bodies, as *oil of vitriol*, or *aqua fortis*. It may be observed, however, that a similar change has taken place in the acceptation of the term *metal*, as in that of *acid*, and that our forefathers would have been as much startled, at seeing placed under that head a body like potassium, which is lighter than water*; or one like arsenic, which is inflammable, and readily volatilized; as the contemporaries of Berzelius were by his application of the term *acid* to silica. In either case, the scientific meaning, conveyed by the words in question, had by degrees been so changed from that which originally had belonged to them, that

* So inseparable, by long association, are the ideas of metallic ponderosity and metallic splendour, that the evidence even of the senses may fail in disuniting them. This is well illustrated in the following amusing anecdote: Shortly after the discovery of potassium, Dr. George Pearson happened to enter the laboratory in the Royal Institution; and upon being shewn this new substance, and interrogated as to its nature, he, without the least hesitation, on seeing its lustre, exclaimed, "Why, it is metallic, to be sure!" and then balancing it on his finger, he added, in the same tone of confidence, "Bless me, how heavy it is!" Paris's Life of Davy, vol. i. p. 268.

they no more express the ideas attached to them by the vulgar, than the sulphur and mercury, in the nomenclature of the alchemist, represented the substances, to which the same names were applied in the common language of the day*.

It ought, however to be recollected, that the apparent inertness of the silicic acid is partly owing to its being known to us chiefly in a solid state. Its action upon the bases, for which it has an affinity, cannot be exerted, until it is rendered liquid, agreeably to the old chemical adage, *Corpora non agunt nisi sint soluta*. Its chemical indifference, therefore, in the state in which we usually perceive it, is no more a proof of its being destitute of acid properties, than the inertness of dry tartaric acid by the side of an alkaline powder would be of the same fact.

At any rate, in whatever light we may regard the propriety of the term, as applied to the substance in question, it is certain that a great point was gained in mineralogy, by establishing, that the earths stand in the relation of acid and alkali one towards the other, and consequently combine together in proportions really as

* The same remark applies to the term 'alcohol,' the meaning of which is explained in the eighth chapter of this work.

definite, as those existing between other binary compounds before investigated.

Thus we have a class of silicates—minerals in which silica acts the part of an acid—corresponding with the sulphates, nitrates, and carbonates which we produce in our laboratories; we find this substance in the proportion of 1, 2, or 3 atoms, forming silicates, bisilicates, trisilicates, as we have sulphates, bisulphates, and the like; and to complete the analogy, we find the silica combined with 2 bases, as with iron and manganese, in a manner corresponding with the double salts, of which we have such frequent examples in chemistry.

Lastly, these compounds are again combined with others similarly constituted, in quantities still retaining with reference one to the other the same relative proportions.

Thus the mineral called cyanite is a silicate of alumina, zircon a silicate of the earth zirconium, diopside a silicate of copper combined with water; whilst by far the greater number of silicious minerals are examples of the kind last alluded to, in which one silicate is united to another. Thus leucite is a silicate of alumina with silicate of lime; natrolite a trisilicate of alumina with a silicate of soda and water.

Twenty years have now elapsed, since Dr. Whewell * presented us with his sketch of a Classification, founded upon the above principles, and sub-

* Dr. Whewell observes, "that if the chemical analogies of each class were completely and certainly known, we might probably express them by means of an algebraical formula, in which some of the symbols might have any of several elementary letters substituted for them. Some of the groups and orders, as garnet, amphibole, zeolite, &c., seem to lead to such expressions. But it seems probable that our knowledge of the analogies among minerals, and of their laws and limits, is at present too imperfect to supply us immediately with most of their formulæ.

"When minerals have been sufficiently examined and studied by accurate and intelligent chemists, *in this point of view*, we may hope to see the subject assume a much greater simplicity and order than we can at present detect. And it does not appear too much to say, that by this means no small light will be reflected back upon chemistry, through the relations thus to be discovered among those ingredients which occupy similar places in our formulæ.

"We find here, for instance, that some oxides of metals, as the *protoxides of iron* and *manganese*, seem to belong to one class of earths, as *lime* and *magnesia*; whilst other metallic oxides, such as the *peroxide of iron*, arrange themselves with a set of earths of a different function, as *alumina*. In the same way we find *phosphoric* and *arsenic* acid occurring analogously; we find in some cases *selenium*, in some *arsenic*, in some *tellurium*, imitating *sulphur* in the properties they impress upon metals by their combination,

"Several other probable connections might be pointed out, but for any thing like a systematic induction of this kind, the subject does not appear yet to be ripe."

sequently to this, Rammelsberg, in his excellent "Hand-book of the Chemical Department of Mineralogy," has arranged all known silicious minerals under certain general heads, grouping them together, according as they are compounds of the silicic acid with one or more bases; according as they are united in the proportion of 1, or a multiple of 1 atom of acid to 1 of base; of 2 atoms of acid to 3 of base, &c.; and according as they are destitute of water, or are combined with it.

This mode of classification would indeed have been impracticable, without the assistance of the law of isomorphism which Mitscherlich has laid down, but knowing, as we now do, that isomorphous bodies may take each other's place, without affecting the crystalline form of the species, we are enabled to account for differences of composition in the same mineral, which completely baffled the ingenuity of the earlier mineralogists.

Thus the following were the results of the analysis of 13 varieties of garnet, made by the Swedish chemist, Wachtmeister, and published in the Stockholm Transactions for 1823.

Table of the composition of 13 varieties of garnet.

	1	2	3	4	5	6	7	8	9	10	11	12	13
Silica	40.60	42.51	41.00	42.00	39.93	35.10	35.64	38.125	37.993	42.450	40.20	40.55	52.107
Alumina	19.95	19.15	20.10	21.000	13.45	—	—	7.325	2.712	22.475	6.95	20.10	18.035
Peroxide of iron	—	—	—	—	14.90	29.10	30.00	19.420	28.525	—	20.50	5.00	—
Lime	—	1.07	1.50	4.980	31.66	26.91	29.21	31.647	30.740	6.525	29.48	34.86	5.775
Magnesia	—	—	6.04	4.320	—	—	—	—	—	13.430	—	—	—
Protoxide of iron	33.93	33.57	28.81	25.180	—	—	—	—	—	9.292	—	—	23.540
Protoxide of manganese } ..	6.69	5.49	2.88	2.375	1.40	7.08	3.02	3.300	0.615	6.273	4.00	0.48	1.745
Potass	—	—	—	—	—	0.98	2.35	—	—	—	—	—	—
Loss	—	—	—	0.145*	—	0.83*	—	0.183*	—	—	—	—	—
Total	101.17	101.79	100.33	100.00	101.34	100.00	100.22	100.000	100.585	100.445	101.13	100.99	101.202

* Including some carbonic acid.

Now it was extremely difficult to understand, upon the old hypothesis, that resemblance in the crystalline form of the minerals here enumerated, which had caused them to be ranged under the same species; but the discovery of Mitscherlich solved the whole mystery, by shewing that all the ingredients are silicates of isomorphous bases, any one of which may be substituted for the rest, without altering materially the standard character of the crystallization.

Thus, in all the varieties of garnet above enumerated except one, it will be seen, that the constituents are, 1 atom of a silicate with some base containing 3 atoms of oxygen to 2 of radical, such as alumina and peroxide of iron, combined with the same quantity of a silicate with a base containing a single atom of oxygen to the same, such as lime, magnesia, protoxide of iron, and protoxide of manganese. Hence in the first instance, the alumina may be substituted for the peroxide of iron, and in the second, the magnesia, protoxide of iron, or the protoxide of manganese for the lime.

In the 13th variety, which cannot be referred to this head, Wachtmeister conceived, that the appearance of the mineral indicates the mechanical admixture of certain foreign substances, and

400 *Isomorphous salts have a tendency to combine.*

hence contended, that its composition ought not to be adduced as invalidating a general law, which twelve other varieties coincide in indicating.

A circumstance, that contributes to render the chemical composition of minerals more complex and diversified, is, the disposition which isomorphous salts appear to have to combine, which is such as to create an extreme difficulty in separating them by artificial means.

“Thus all the species of alum (observes Beudant*) have so strong a tendency to mix together, that it is very difficult to counteract it, neither, when once united, can they be completely separated, even by repeated crystallizations. Mixtures of the same kind occur, between nitrate of baryta and nitrate of lead; between the nitrates of potassa and soda; between the sulphates of iron, cobalt, nickel, &c.; and between the sulphates of zinc, soda, and magnesia, &c. &c. These mixtures occur, not only when a solution contains merely the salts of the abovementioned group, but are even found in preference if a great number of salts be dissolved in the same liquid; so that it may be said, that salts belonging to the same order of composition seek each other, as it were,

* Mineralogie, p. 399.

so as to crystallize together, and mix in every proportion."

In the earliest memoir on chemistry which I ever published, relating to the methods of separating lime from magnesia*, I pointed out the difficulty which occurs, in separating *completely* by the usual re-agents magnesian salts from calcareous ones, or *vice versa*.

Thus for example it would appear from my experiments, that a solution, consisting of 1 grain of sulphate of lime, and 100 grains of sulphate of magnesia, in one ounce measure of water, was not rendered turbid by oxalate of ammonia till many hours afterwards, although the same solution of lime, without the magnesia, became so immediately under the same treatment.

For the same reason it would appear, if my experiments are to be relied on, that bicarbonate of ammonia, which with magnesia alone forms a compound readily soluble in water, when added to a solution containing a magnesian as well as a calcareous salt, carries down a small portion of the magnesia with the carbonate of lime precipitated.

Now as the salts of lime and of magnesia are isomorphous, we may perhaps account for the difficulty of completely separating them by chemical

* In the Edinburgh Philosophical Journal, vol. vii. 1822.

re-agents, on the same principle, by which their tendency to crystallize together is to be explained.

The above considerations are sufficient to vindicate the soundness of the principle on which Berzelius has proceeded, and to induce us to adopt it as the basis of a natural system of mineralogy, to which purpose Rammelsberg has applied it.

A classification of minerals, indeed, founded on their chemical constitution, although totally inefficient as a means of discriminating species, and therefore altogether unfitted for the purposes of an artificial system, is perhaps a more natural one even than that framed from considering the analogies of crystalline form, since the former is the bare expression of their fundamental differences and analogies, the latter only of one of the consequences flowing from them.

A system too that should be based on differences of crystallization would embrace after all but a part of the subject itself, since many bodies occur constantly, and a still larger proportion of them occasionally, in an amorphous condition; so that we should be driven in such cases to have recourse to other characters, less susceptible of precision, and subject to a greater degree of variation.

It is also certain, that a classification established

on chemical principles, conveys with it information of more general interest, both in a scientific and practical point of view, than one dependant on the external characters merely; for without in any degree wishing to underrate the value of crystallography, considered as a beautiful application of mathematical principles to an elucidation of the relations subsisting between the forms exhibited by the same mineral species, it must be admitted, that a chemical classification is best adapted to the great mass of mankind, who resort to a system of mineralogy, as a store-house of information, with respect to the uses, the intimate nature, and the chemical relations of the substances enumerated.

It appears to me, therefore, that Rammelsberg's classification may be in some measure regarded as realizing those anticipations, which in my former edition I ventured to hold out, namely, that it might be possible at some future period to frame a system of mineralogy, combining the advantages of a natural as well as an artificial method, which should be based entirely on the atomic constitution of bodies, and the doctrine of isomorphism, which has proceeded from it, thus affording additional proof of the widely spreading influence of this discovery.

In illustration of these remarks, I will here subjoin the following outline of Rammelsberg's method:—

CLASS I.

Silicic acid, with a single base containing 1 atom of oxygen



WITHOUT WATER.

Example :



WITH WATER.

Example :



II.

Silicic acid, with a single base containing 3 atoms of oxygen to 2 of the radical



WITHOUT WATER.

Example :



* In this Table, it will be perceived, that I have adopted, for the sake of brevity, the short-hand method of notation which Berzelius proposed. See p. 110.

WITH WATER.

Example :



III.

Silicic acid, with several bases all containing 1 atom of oxygen



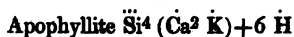
WITHOUT WATER.

Example :



WITH WATER.

Example :



IV.

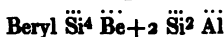
Silicic acid, with several bases all containing 3 atoms of water to 2 of radical



* When several symbols are placed within brackets, it is implied, that the bodies represented may replace each other, without affecting the form of the mineral species. Thus augite consists of 1 atom of silicic acid united to 3 atoms, either of lime, magnesia, protoxide of iron, or protoxide of manganese.

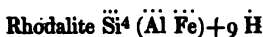
WITHOUT WATER.

Example :



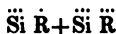
WITH WATER.

Example :



V.

Silicic acid, with several bases, some with 1 atom of oxygen to 1 of radical, others with 2 of oxygen to 3 of radical.



This class, being very numerous, is not only subdivided into 2 orders, like the rest—that with, and that without water—but is likewise broken into other subordinate groups, according to the proportion which the silicic acid bears to the base with which it is combined.

Thus, amongst those minerals which are *destitute of water*, we recognise the following distinctions :

a.

$\ddot{\text{Si}}$ neutral with * all the bases.

* According to Berzelius, whom Rammelsberg follows, a

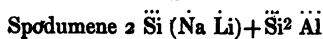
Example :



b.

$\ddot{\text{Si}}$ neutral with $\dot{\text{R}}$; in the proportion of $\frac{2}{3}$ with $\underline{\ddot{\text{R}}}$

Example :



c.

$\ddot{\text{Si}}$ neutral with $\dot{\text{R}}$; as $\frac{1}{3}$ with $\underline{\ddot{\text{R}}}$

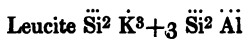
Example :



d.

$\ddot{\text{Si}}$ in the proportion of $\frac{2}{3}$ to both bases.

Example :



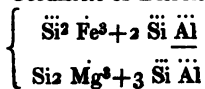
e.

$\ddot{\text{Si}} \frac{2}{3}$ to $\dot{\text{R}}$; $\frac{1}{3}$ to $\underline{\ddot{\text{R}}}$

neutral silicate must contain 3 atoms of silicic acid, when the base contains 3 atoms of oxygen ; and 1 of acid, when the base contains only 1 of oxygen.

Example:

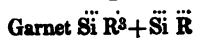
Cordierite or Dicroite=



f.

$\ddot{\text{Si}}$ as $\frac{1}{3}$ to both bases

Example:



g.

$\frac{1}{3}$ to $\ddot{\text{R}}$; $\frac{1}{6}$ to $\underline{\ddot{\text{R}}}$

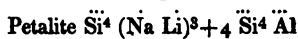
Example:



h.

$\ddot{\text{Si}}$ as $\frac{1}{3}$ to both bases

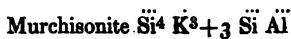
Example:



i.

$\ddot{\text{Si}}$ $\frac{1}{3}$ to $\ddot{\text{R}}$; $\frac{1}{3}$ to $\underline{\ddot{\text{R}}}$

Example:



The silicates *that contain water* may be divided, into those in which the water is simply united to the silicic combination, and those in which it acts the part of an acid with some base, together forming an hydrate; the latter being combined with the double silicate.

The former combinations are called hydrosilicates; the latter are distinguished as silicates with hydrates.

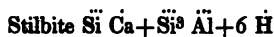
1st.

Hydrosilicates.

a.

$\ddot{\text{Si}}$ neutralizing both bases.

Example :



b.

$\ddot{\text{Si}}$ neutral with $\dot{\text{R}}$; $\frac{2}{3}$ with $\ddot{\text{R}}$

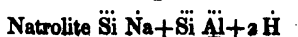
Example :



c.

Neutral with $\dot{\text{R}}$; $\frac{1}{3}$ with $\ddot{\text{R}}$

Example :



d.

$\ddot{\text{Si}}$ neutral with $\dot{\text{R}}$; $\frac{1}{4}$ with $\ddot{\text{R}}$

Example :

Pinguite $\ddot{\text{Si}} \dot{\text{Fe}} + \ddot{\text{Si}}^3 \ddot{\text{Fe}}^2 + 15 \dot{\text{H}}$

e.

$\ddot{\text{Si}}$ $\frac{2}{3}$ rd with both bases.

Example :

Analcime $\ddot{\text{Si}}^2 \text{Na}^3 + 3 \ddot{\text{Si}}^2 \ddot{\text{Al}} + 6 \dot{\text{H}}$

f.

Acid $\frac{2}{3}$ rd with $\dot{\text{R}}$; neutral with $\ddot{\text{R}}$

Example :

Sphærostilbite $\ddot{\text{Si}}^2 \dot{\text{Ca}}^3 + 3 \ddot{\text{Si}}^3 \ddot{\text{Al}} + 18 \dot{\text{H}}$

g.

Acid $\frac{2}{3}$ rds with $\dot{\text{R}}$; $\frac{1}{3}$ rd with $\ddot{\text{R}}$

Example :

Fahlunite (*Thomson*) $\ddot{\text{Si}}^2 (\dot{\text{Mg}} \dot{\text{Fe}})^3 + 3 \ddot{\text{Si}} \ddot{\text{Al}} + 2 \dot{\text{H}}$

h.

Acid $\frac{1}{3}$ rd to both Bases.

Example :

Thomsonite $\ddot{\text{Si}} \text{Na}^3 + 3 \ddot{\text{Si}} \ddot{\text{Al}} + 3 \dot{\text{H}}$

i.

 $\ddot{\text{Si}} \frac{1}{3}\text{rd with } \dot{\text{R}}; \frac{1}{6}\text{th with } \ddot{\text{R}}$

Example :

 Chloritespar (*Bonsdorff*) $\ddot{\text{Si}} (\dot{\text{Fe}} \dot{\text{Mg}})^3 + \ddot{\text{Si}} \ddot{\text{Al}}^2 + 9 \text{ H}$

j.

 $\text{Si} \frac{1}{3} \text{ with } \dot{\text{R}}; \frac{2}{3} \text{ with } \ddot{\text{R}}$

Example :

 Datolite $2 \ddot{\text{Si}}, \dot{\text{Ca}}^3 + \ddot{\text{Si}}^2 \ddot{\text{B}}^3 * + 3 \text{ H}$

k.

 $\ddot{\text{Si}} \frac{1}{4} \text{ with } \dot{\text{R}}; \frac{1}{3} \text{ with } \ddot{\text{R}}$

Example :

 Prehnite $\ddot{\text{Si}}, \dot{\text{Ca}}^2 + \ddot{\text{Si}} \ddot{\text{Al}} + \text{H}$

l.

 $\ddot{\text{Si}} \frac{1}{3} \text{ to both bases.}$

Example :

 Neurolite $\ddot{\text{Si}}^4 (\dot{\text{Ca}}, \dot{\text{Mg}})^3 + 5 \ddot{\text{Si}} \ddot{\text{Al}} + 6 \text{ H}$

m.

 $\ddot{\text{Si}} \frac{1}{3} \text{ to } \dot{\text{R}}; \frac{2}{3} \text{ to } \ddot{\text{R}}$

Example :

 Harmotome $2 \ddot{\text{Si}}^4 (\dot{\text{Ba}}, \dot{\text{K}}) + 7 \ddot{\text{Si}}^2 \ddot{\text{Al}} + 36 \text{ H}$

* $\ddot{\text{B}}$ (Boracic acid) being here considered to act as a base.

n.

 $\ddot{\text{Si}} \frac{1}{4} \text{ with } \underline{\text{R}}; \frac{3}{4} \text{ with } \underline{\underline{\text{R}}}$

Example :

 $\text{Onkosin } \ddot{\text{Si}}^5 (\dot{\text{K}}, \dot{\text{Mg}}) + 6 \ddot{\text{Si}} \ddot{\text{Al}} + 3 \text{H}$

2ndly.

Silicates with hydrates.

 $\text{Ripidolite (chlorite) } \ddot{\text{Si}} (\dot{\text{Mg}}, \dot{\text{Fe}})^3 + \ddot{\text{Si}}, \ddot{\text{Al}} + 3 \text{H}, \text{Mg}$

VI.

Silicates with aluminates.

Example :

 $\text{Staurolite (v. Kobell) } 3 \ddot{\text{Si}} \ddot{\text{Al}} + \ddot{\text{Al}}^2 \text{Fe}^3$

VII.

Silicates with sulphates, phosphates, carbonates, chlorides, fluorides, and sulphurets.

WITH SULPHATES.

Example :

Häüyne (v. Kobell) $\ddot{\text{Si}}^2 \text{Ca} + 3 \ddot{\text{Si}} \ddot{\text{Al}} + 2 \ddot{\text{S}} \dot{\text{K}}$, but Rammelsberg conceives that in this mineral $\ddot{\text{S}}$ may replace $\ddot{\text{Si}}$ throughout.

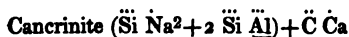
WITH PHOSPHATES.

Example :

 $\text{Sordawalite } \ddot{\text{Si}}^2 (\dot{\text{Mg}} \dot{\text{Fe}}) - \ddot{\text{Si}}^2 \ddot{\text{Al}}, \text{ mixed with } \ddot{\text{P}} \dot{\text{Mg}} + \text{H}$

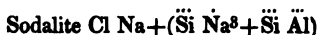
WITH CARBONATES.

Example :



WITH CHLORIDES.

Example :



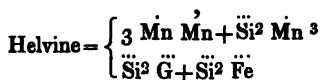
WITH FLUORIDES.

Example :



WITH METALLIC SULPHURETS.

Example :



The above may serve as a brief sketch of the best chemical arrangement perhaps of silicious minerals that has as yet been offered ; and it may not be amiss, for the sake of those who are disposed to undervalue the minute distinctions set up in it between the combinations of silicic acid with the various bases, to notice in this place some researches of a more general bearing, but connected with the same subject, by means of which a distinguished German chemist and naturalist, Abich,

414 *Difference in the composition of felspars.*

has succeeded in throwing much important light upon the formation of the globe, and on the nature of those igneous processes to which its crystalline portions owe their origin, through a minute examination of the relative proportions of acid and base subsisting between different minerals belonging to the Felspar Family.

Abich has shewn, that orthoclase, the description of felspar which predominates in granite, is more highly charged with silica than those kinds which are found in rocks of reputed volcanic origin, and that in the former mineral the bases are combined with the largest amount of silica which they are capable of retaining, the proportion being 3 of silica to 1 of base.

Nevertheless, in granitic rocks there is always a considerable proportion of quartz, or of uncombined silica, shewing, that there was after all more of the latter acid present, than could find any substance with which to combine.

This however will be best shewn by the following Table, in which a view is given of the chemical constitution, specific gravity, &c. of the mineral species comprehended under the Felspar Family ;

Tabular view of the chemical constitution, specific gravity, &c. of the mineral species compared from Abich, Ueber die natur der vulkan. bildungen, 1841.

Name.	Rock.	Locality of the specimen analysed.	Specific Gravity.	Principal Constituents.			Formula.
				Silica.	Alum.	Lime. Potass. Soda.	
Potass-albite	Granite & Trachyte	Drachenfels	2.6223	70.22	17.29	2.09	5.62
Soda-albite	Granite .....	.....	2.6140	69.36	19.26	0.46	10.50
Periclinae	Granite & Trachyte	Pantellaria	2.6410	67.94	18.93	0.15	9.98
				68.23	18.30	1.26	7.99
Glassy or Soda Felspar	Trachyte	Ischia	2.5970	66.73	17.56	1.23	4.10
Orthoclase	Granite	Baveno	2.5552	65.72	18.57	0.34	1.25
Adularia	Granite	St. Gothard	2.5756	65.59	17.97	1.34	1.01
Artificial Felspar .....	.....	Made at Sangerhausen.	2.5600	65.03	16.84	0.34	0.65
Oligoclase	Granite .....	.....	2.6680	62.61	24.11	2.74	8.89
Andesin	Trachyte	Popayan, Andes	2.7328	59.60	24.28	5.77	6.53
Labradorite	Basalt and Porphyry	Mount Etna	2.7140	53.48	26.46	9.49	4.10
Rhycolite	Lavas	Monte Somma	2.6180	50.31	29.44	1.07	10.56
Anorthite	Lavas	Monte Somma	2.7630	43.79	35.49	18.93	0.68

The minute quantities of peroxide of iron and of manganese, of titanate acid and of magnesia, are not stated.

Now it is to be observed, that all those minerals, that contain the largest per centage of silica, are obtained either from granitic, or from trachytic rocks, an additional evidence of the derivation of the latter from the former.

Trachyte, however, more commonly contains little or no quartz, so that the redundant silica appears to have been saturated by some base. In a few instances, as in potass-albite, and in pericline, this base would seem to be partly soda and partly potass. These minerals, however, occur but rarely, except in granite; whilst in others, as in glassy felspar, which is the most abundant ingredient of trachytic rocks, although potass still predominates, there is more soda than in orthoclase and adularia, the minerals usually found in granite.

Hence it may be inferred, that when trachytic was formed the granite must have undergone a second fusion in the presence of a certain amount of soda, and that this alkali had seized upon the uncombined silica existing in the quartz, thus giving rise to a rock consisting almost wholly of glassy felspar.

At any rate, the increase of lime in the felspar derived principally from volcanic rocks of more recent origin is very remarkable, and no less so, is the diminution from 3 to 1 atom of the silicic acid, in proportion to the quantity of base which is observed in their latter formation.

Recent lavas indeed are made up principally, of labradorite, a silicate with 1 atom only of acid, and of hornblende or augite, two minerals chemically the same, although crystallographically different, in which the silicious ingredient is in general wholly saturated with lime, magnesia, protoxide of iron, or protoxide of manganese, the exclusion of alumina indicating the increased quantity of the former bases superadded to the original granitic material.

Two other facts of some significance are, the existence of iron wholly in the state of a peroxide in granite, whilst it is partially in that of protoxide, or in the condition of magnetic iron ore ($\text{Fe} \overline{\text{Fe}}$), in lava; owing probably to the deoxidising influence of the hydrogen and its compounds so freely given out by volcanos; as likewise the presence of water in basalt, a rock which is regarded as an intimate mixture of augite and magnetic iron, with a mineral of the zeolitic family, whilst it is altogether absent from the products of subaërial volcanos.

The composition indeed of this zeolitic mineral is such as to imply, that it may have been formed out of labradorite by the addition of water, the presence of which in all zeolites is the cause of that bubbling up under the blow-pipe, which has occasioned them to be distinguished by this general appellation.

We perceive a similar change in the rock called clinkstone, which has been shewn by Gmelin to be an intimate mixture of glassy felspar with a zeolite; so that it seems to bear the same relation to trachyte, which basalt does to augite rock, or to dolerite.

In proceeding then onwards towards the more modern groups of volcanic formations, we find new ingredients successively coming into play; first, the alkalies increasing; then lime and magnesia becoming part of the constitution of the mineral mass; and lastly, water entering into combination with the earthy materials.

The gradual increase of soda is likewise a remarkable circumstance, modern lavas appearing to contain a much larger quantity of it than the volcanic products of ancient periods; and various minerals being hence produced, as natrolite, nepheline, thomsonite, &c. in which this alkali is predominant.

For a more detailed statement of the above facts and for their application to the chemical theory of volcanos, which they appear to me to corroborate, I must refer my readers to my general Work on that subject*; and shall only further remark, that even those who may dispute their validity with reference to this view of the causes

* Description of Active and Extinct Volcanos. 8vo. London, 1847.

of the phenomena in question, must admit, that the distinction thus shewn to exist, between the nature of the products that present themselves in granitic, and in volcanic formations, is one which ought by no means to be lost sight of in framing a Theory of the Earth ; and thus will serve equally to illustrate the utility of those minute chemical investigations, which the study of the Atomic Theory tends to encourage, and indeed alone renders it possible to prosecute with success.

Thus every thing which mineral chemistry reveals to us concurs in proving, that the law of definite proportions extends throughout the whole of inorganic matter.

Neither are vegetable or animal products exempt from its influence, although a provision exists, according to the ingenious views of Dr. Prout, for preventing its interference with the operations of life ; a minute portion of some foreign matter being superadded to every definite compound intended to be assimilated, which, either by the interposition of its particles, or perhaps in some other less intelligible way, counteracts the operation of that cohesive attraction, the tendency of which is to impart somewhat of a crystalline character to the mass.

Bodies containing this admixture of foreign

matter in infinitesimal quantities he denominated *merorganised*, in order to express this supposed condition, implying by it, that in passing into this state they have become partly, or to a certain extent, organised. Thus starch, according to Dr. Prout, would be *merorganised* sugar, differing from the latter by the presence of certain foreign matters, which effect a complete change in its character.

It is with this intent perhaps, that minute, and sometimes almost infinitesimal quantities of sulphur and phosphorus, enter into the composition of the so-called proteine compounds, which serve to make up the softer portions of the animal frame; whilst the solid parts derive their consistency, not from carbonate of lime, but from the phosphate, intermixed with a very minute quantity of fluuate of lime, which I have found to be generally present in bones, whether recent or fossil*; and which therefore may possibly possess some use, in counteracting that tendency to crystallization in the phosphate, which would interfere with its fitness to form the material of our bones.

* See my paper in the Memoirs of the Chemical Society of London, vol. ii., read March 18, 1844. The general presence of fluorine in bones has since been confirmed by Mr. Middleton. See his paper in the same work bearing the date of May 6, 1844.

It would, doubtless, be unphilosophical to attribute to the self-same law of nature, the proportion existing between the particles that compose a compound body, and the relation of number that has been traced amongst the parts of the floral organs in plants ; yet it may not be without interest to notice, as a proof of the analogy which runs throughout the whole of creation, and as indicating perhaps, that the law of definite proportions itself, widely spreading as it seems, is but one of the consequences of some more comprehensive principle, the conclusions which the most distinguished botanists have arrived at, as to what ought to be regarded the primitive types of monocotyledonous, dicotyledonous, and acotyledonous plants ; these constituting the three great classes into which the vegetable kingdom may be divided.

The elder Decandolle, in his admirable Essay on the Principles of Philosophical Botany*, drew attention to the fact, "that the numbers 4, 5, and their multiples, appear to belong peculiarly to dicotyledonous plants ; the number 3, and its multiples, to monocotyledonous ; the number 2, and its multiples, to be established among the acotyledonous in the great family of mosses." That exceptions from this standard are numerous,

* *Théorie Element.* p. 157.

will be evident, when we recollect, that the main principle, on which the artificial arrangement of Linnæus proceeds, is founded on a difference of number in the floral organs; but it is now generally admitted, that these deviations from the supposed standard may be explained by the interference of other causes, such as the abortion of certain parts, or the adhesion of two or more, so as to have the appearance of one; whilst the existence of the same tendency towards regularity may be traced even in these, by an occasional return to the ideal structure, whenever the causes which usually interfere with it are accidentally removed.

Mons. Decandolle has also shewn, that this numerical proportion exists between the members of the different organs that together constitute the same flower, as well as between the component parts of different flowers belonging to the same class.

Thus the relation of number between the parts of the calyx and corolla is very remarkable; and the deviations from this regularity that are met with, may be referred to the causes above assigned; being most frequent where the parts are most numerous, the chances of abortion or of adhesion being increased in proportion.

The same relation extends likewise to the stamens, subject to occasional deviations; and even

in the pistillary system, which presents the greatest anomalies in this respect, it may be observed, that the number of the valves of the pericarp, of the placenta, of the pistillary chord, of the styles, and the stigmas, &c., is always in the proportion of 1 to 1, 1 to 2, 2 to 1; so that one of these organs may serve to determine the rest, allowing for exceptions from abortion, &c.; and that when the parts of the pistils are disposed in a whorl-shaped manner around an ideal or real axis, the number of their parts is in a determinate relation to that of the other parts of the flower, this relation being one of the following :

1 to 1	2 to 5 or its multiples.
1 — 2 or its multiples.	3 — 5 or ditto.
1 — 3 or ditto.	4 — 5 or ditto.
1 — 5 or ditto.	2 — 1.
2 — 3 or ditto.	

Lastly, we learn from astronomers, that the members of the planetary system to which we belong, are themselves subject to a law of an analogous kind.

Bode observed, that the magnitudes of the several orbits which the planets describe, bear a certain definite proportion one to the other, the distances of Mercury, Venus, the Earth, Mars, &c. from the sun, being that of the numbers 4, 7, 10, 16, 28; so that the differences are as 3, 3, 6, 12.

The law was interrupted between Mars and Jupiter, so as to induce him to consider a planet as wanting in that interval; a deficiency long afterwards supplied by the discovery of four new planets in that very interval, all of whose orbits conform in dimension to the law in question, within such moderate limits of error, as may be due to causes independent of those on which the law ultimately rests*.

There cannot be a sublimer subject for contemplation, or one more calculated to elevate our ideas with respect to the Divine attributes, than the correspondence, which may thus be traced between the laws that pervade the whole of creation, from the ultimate particles of matter, which, by their extreme minuteness, baffle our very powers of conception, to those immense aggregates of them, which compose any one of the members of our own planetary system; and as, according

* In the 3rd volume of the Cambridge Transactions, Mr. Challis has attempted to extend Bode's law of the distances of the planets from the sun, to the distances of the satellites from their respective primaries. He shews that the differences of the distances of Jupiter's satellites, are very nearly in the ratio of $2\frac{1}{2}$; those of Uranus in that of $1\frac{1}{2}$; authorizing the conjecture, that there are two undiscovered satellites between the 4th and 5th, and one between the 5th and 6th. In the case of Saturn's satellites, the ratio is further departed from, perhaps from the interference of the ring.

to the grand conception of Boscovich, the attraction of gravitation, and that of cohesion, may perhaps turn out to be the same force exerted at different distances ; so the various ways, in which, as we have seen, the tendency to definite proportions (if I may so express myself) manifests itself throughout the whole of nature, will perhaps be eventually traced to the same law ; of which, what is called the atomic theory, comprehensive as it may be, is only one of the consequences.

It is this indeed which constitutes the most striking distinction between the effects of art and of nature, the provisions of finite and of infinite intelligence ;—the former accomplishing its purposes by a multitude of particular contrivances and regulations, which being made to meet each circumstance as it arises, are inconsistent one with the other, and at the best are applicable to a limited number only, out of the infinite variety of possible cases ;—the other producing an immense series of effects by a few very simple laws, which not only at the time display an exact harmony, but afterwards, as we proceed in their investigation, are found to be the consequences of a still smaller number of first principles.

CHAPTER XIII.

SPECULATIVE INQUIRY INTO THE ELEMENTS OF MATTER.

Opinions of the ancients with respect to the elements of matter—Whether several elementary kinds of matter were previously created, and other bodies formed by the union of these—or whether all substances are produced from one elementary matter, and derive their properties from the different aggregation or arrangement of their particles—Arguments in favour of the latter hypothesis—Experiments of Dr. Brown—Speculations of Professor Lowe on this subject—Objections to their views—Arguments *à priori* on such a question unsatisfactory.

IN the preceding chapters of this work I have dealt with the Atomic Theory as a branch of modern philosophy, confining myself to those deductions from ascertained facts which may be ad-

vanced with some degree of confidence, and may be regarded, as it were, a part of the present patrimony of science.

But before I conclude, it may be permitted, that some further notice should be taken, of those speculations in which the ancients indulged on this subject, and of the confirmation which some of them may appear to have received from the researches of the moderns.

We still, for instance, seem balanced between the two opinions which divided the ancient world, as to whether the particles of bodies all belong to one original kind of matter, the *πρώτη ὕλη* of the Greeks, impressed with certain distinct properties, or with various modifications of the same—or whether, as other philosophers imagined, there were several elementary kinds of matter originally produced, which, by their intermixture and union, gave rise to the infinite variety of appearances which diversify the face of creation.

The latter, indeed, is the most easily intelligible hypothesis, and is moreover favoured by the fact, that the products of the animal and the vegetable kingdoms are all ascertained to arise out of a very few simple principles.

It would also be somewhat confirmed, if it should turn out that the atomic weights of the

different bodies, which we regard as simple, bear a numerical proportion one to the other; an opinion which may still be tenable, even if it should be shewn, that the doctrine suggested by Prout, and supported experimentally by Thomson, as to their being all multiples of hydrogen, is to be viewed as erroneous*.

On the other hand, it must be confessed, that the progress of discovery, instead of bringing us nearer to the knowledge of these elements, increases the difficulty of even conjecturing what they are likely to prove.

We are warned, indeed, against attaching an undue importance to such speculations, by the fate that has attended the doctrine, which as-

* I have stated in a note to chapter IX. that Persoz resolves chemical affinity into a mechanical fitness in the particles to cohere. Supposing then all matter to be originally the same, and the properties of other bodies to arise out of the mechanical arrangement of the particles of this primary matter, it is conceivable, that other bodies may be produced by the aggregation of different numbers of these atoms, and that certain numbers, when brought together, may cohere with a force which no chemical agency can ever separate. On this assumption, such aggregates of particles of the primary matter would be *quoad nos* elements, and moreover their atomic weights would necessarily be multiples of that of hydrogen, supposing this to be the lightest body in nature.

sumed the elements of earth, air, fire, and water, as the basis of all existing substances; a notion introduced, as we have seen, into Greece by the Pythagoreans, but which appears to have been held, both in Egypt, and in India, for a long time previous to the epoch at which they flourished.

Venerable from its antiquity, and plausible from the resemblance borne by all natural substances to one or other of these elementary forms of matter, it was adopted even in modern times, as the established creed by most persons of education; and even at the present day it is firmly rooted in the minds of the multitude, who, in philosophy, in medicine, and in all other subjects, adopt the exploded theories of the age antecedent, just as the lower orders are wont to bedeck themselves in the cast-off habiliments of their betters.

We however have lived to see every one of these supposed principles reduced to other simpler kinds of matter; whilst the bodies, that have most effectually baffled our powers of analysis, are often very scantily diffused throughout nature, and very limited in the range of their affinities.

Yet if they are compounds, it might be ex-

pected that, like the products of the animal and vegetable kingdoms, they should be found occasionally convertible one into the other, if not by the powers of art, at least by the agency of natural causes ; and the unchangeableness of their properties might therefore lead us to conjecture, that they are to be viewed rather as modifications of one primary matter, impressed by the Creator with characters sufficiently distinct to give each of them a place as a separate and independent body, but yet so far approaching one to the other, as to constitute them links of a common series.

This view of the subject might be preferred by those who contend for the law of continuity laid down by Leibnitz, to which Boscovich has taken so much pains to accommodate his system ; for if, according to this doctrine, nature does nothing *per saltum*, but passes from one change to another by minute and imperceptible gradations, it would seem more agreeable to analogy to suppose a series of elementary substances, whose properties, like those of the metals, approach very near to one another, than to imagine only three or four so strongly contrasted in their nature, as the more common opinion assumes*.

* The curious researches of Cagniard de la Tour afford a

The facts, indeed, relating to isomerism, which were alluded to in my seventh and eighth chapters, seem to lend some colour to this hypothesis ; since, if it can be shewn, that in compound bodies a mere variation in the arrangement of the same particles is sufficient to produce an entirely different material, substances which from having resisted our powers of decomposition, we regard as simple, may themselves be isomeric, or produced by a different arrangement of the same elementary matter.

We have seen, indeed, that several belonging to this class of bodies are dimorphous, that is, capable of assuming two different crystalline

considerable confirmation of the law of continuity ; they shew, that as the solid condition passes by imperceptible gradations into the liquid, so does the liquid into the æri-form ; whilst the more recent ones of Mr. Faraday indicate, that the property of existing in a gaseous state is the exclusive condition of none, and that, as all bodies may be fused and probably volatilized by the addition of heat, so there are none, that may not be made to pass into a liquid or solid state, by its abstraction. Is it not probable, that future discoveries may also point out links connecting all the simple substances into one uniform series, as the researches of the geologist, combined with those of the comparative anatomist and the vegetable physiologists, bid fair to do with regard to the families composing the animal and vegetable kingdoms ?

forms; yet from this difference of structure no alteration of chemical properties results.

But by assuming them to be compounds, and by supposing the elements of which they consist to undergo the same kind of transposition, which takes place in the instance of many known to be compounds, we may figure to ourselves the possibility of the formation of the metals, the simple combustibles, and the supporters of combustion, all out of the same constituents.

It has been found, that cyanogen, a body known to be compound, bears the same chemical relation to hydrogen and other simple combustibles, which oxygen and chlorine possess; there is therefore nothing at least contrary to analogy in supposing, that other bodies which stand in the same relation may likewise be compounds.

Cyanogen exists under two different forms, and so likewise do sulphur and carbon.

One of the forms in which cyanogen exists is as a gas, the other as a solid. There is therefore as great a difference in physical properties produced in cyanogen, as exists between any two of the bodies regarded as elementary, between iodine and bromine, for instance; or between oxygen and sulphur. If such a change in physical properties can result from *dimorphism*, why may not

an equal difference in their chemical properties be occasioned by that transposition of their ultimate component parts which takes place in *isomeric* bodies, if only we suppose them to be compound? And if that class of bodies, which stands in the same relation to them in the vegetable and animal kingdoms, be of a compound nature, is there not at the least a probability, that the same may turn out to be the case with the radicals of mineral bodies also?

Before however we yield our final assent to so bold an hypothesis, and assume, that the so-called elements of matter are constituted of the same particles differently arranged or aggregated, we should take into account another class of phenomena which point rather to the opposite conclusion; as they shew that when simple bodies have their mechanical condition altered, no such radical change in their properties does ensue.

I will not here allude to the common case of the conversion of a solid into a liquid, and of a liquid into a gas; but I will briefly point out a few of those instances, in which a simple substance still retaining its solid form is submitted to treatment, by which its mechanical condition, and

those physical properties, such as colour, hardness, &c., which are consequent upon the former, become visibly changed.

The most remarkable case of the kind yet known to us is phosphorus, which, according to Professor Schrötter of Vienna, is converted into a red powder destitute of crystalline structure, either by exposure to light, or by the long continued action of a heat not exceeding 450° of Fahr., oxygen being in both cases excluded.

If the mechanical properties alone were altered by the treatment, the change might be regarded as a simple case of dimorphism, but its chemical ones are also to a certain extent affected, for amorphous phosphorus is not soluble either in sulphuret of carbon, in ether, or in alcohol, all which dissolve it under ordinary circumstances.

Its inflammability also is considerably impaired, nor does it shine in the dark at common temperatures, as phosphorus usually does.

Hence Berzelius has proposed to designate by the term *allotropic*, substances susceptible of these modifications, at once of form, and of chemical properties; and he instances sulphur, and carbon, as other simple bodies which present the same or similar variations, sulphur appearing in the form

of octaedra and of prisms, and also in an amorphous or plastic condition—carbon existing as diamond, as graphite, and as charcoal.

I am not aware, however, that these two bodies undergo corresponding chemical changes according as their physical properties become modified, and hence would propose to restrict the term *allotropism* to such cases as phosphorus, considering what takes place in the instances of carbon and of sulphur as belonging to the category of *dimorphism*.

Now the phenomena above alluded to, although at first sight they may appear rather favourable than otherwise to the notion, that the chemical properties of a body are referable to its mechanical state alone, when more attentively considered, will be found at variance with it; not only because they prove, that a difference in the mechanical arrangement or grouping of the particles of a substance, sufficient to alter completely its colour, consistency, and general structure, produces only a slight modification in those chemical properties which characterise it as a distinct substance; but likewise because the readiness with which an allotropic body passes again and again from one of its phases into another, is utterly at variance with that fixity of constitution, which belongs to the so-called elements, and which

renders even those that present the nearest resemblance, such as platinum and palladium, zinc and cadmium, as little capable of being made to pass one into the other, by the manipulations of the Chemist, or even through the agency of that more subtle Alchemist Time, as are those elements which seem most contrasted and antagonistic.

Such were the conclusions, to which I had arrived at the period of the publication of the first edition of this Essay, and to which I adhered in the Supplement which appeared seven years afterwards; nor do I see anything in what has been revealed to us by more recent investigations, which should lead to a modification of my views in this respect.

Two attempts indeed to shake our faith in the elementary nature of the bodies that still remain undecomposed, have since emanated from Edinburgh—the one experimental, by Dr. Brown, in which the conversion of carbon into silicon, and of iron into rhodium, is asserted as having been actually accomplished; the other theoretical, by Professor Lowe, founded upon general reasoning, and on the analogies between the so-called elements.

It is not my intention to speak otherwise than

with respect of either of these authors; more especially in alluding to the inquiries of my worthy colleague in the Chair of Rural Economy, who has fairly earned the privilege of roaming through the more speculative regions of philosophy, by his previous labours in the practical field of scientific agriculture.

Neither perhaps is it amiss, that the cultivators of science should occasionally have familiar facts presented to them under a new aspect, or should be reminded, that the principles upon which they are accustomed to build, are based upon postulates which some are still tempted to impugn.

With respect however to Dr. Brown's experiments, it may be enough to remark, that considering the paradoxical conclusions to which they lead, we should be slow, even if the highest authorities in science were to vouch for their correctness, in admitting their *sufficiency*, until they had been confirmed by other independent trains of research.

It is at any rate too much to expect, that one or two experiments, which were conducted on so small a scale, as to create a difficulty in determining the real nature of the products, and which have never yet been successfully repeated by others, should be allowed to vitiate the whole tenor of our former results, and to overturn the

entire fabric of the science, which is based upon the presumption that such bodies are elementary.

Nor will many be found to maintain, that, supposing the two modes of considering the constitution of matter, which have been above pointed out, are possessed of nearly equal probability, the arguments of Professor Lowe have sufficient weight to strike the balance in favour of the theory he advocates.

There is indeed no difficulty, in deriving all the other simple bodies, from any two in the list whose atomic weight happens to be lowest.

No problem can be simpler than this, provided we take the liberty of dropping the fractional parts, and set these down to errors in experiment; so that it would have been just as possible to have deduced the composition of the so-called elements from hydrogen and oxygen, as from hydrogen and carbon, the two bodies which Professor Lowe has chosen to select.

Indeed, as I have already shewn in a note, the derivation of all the supposed elements from one primary matter is quite as easy, and perhaps even more philosophical.

Hydrogen 2 atoms, carbon 1, are supposed by the author to form oxygen, $H_2 C_2$, nitrogen,

H₄ C₂ sulphur, and so on; but it is evident, that by a little alteration in the equivalent numbers, by doubling the atom and so forth, it would be equally possible to conceive them derived from hydrogen and oxygen.

In either instance, however, the question recurs, why are these combinations so much more stable, than others which are framed artificially out of the same elements, and which present apparently the same proportions?

Thus from H₂ C we form marsh gas; a compound, not only as different as possible from oxygen, but also very easily resolvable into its own component parts.

It is plain therefore, that the sort of combination between these two elements, which is supposed by professor Lowe to take place, when a body like oxygen is formed through it, must be totally distinct in its nature, from that which binds them together, when they constitute the compound artificially produced out of the same ingredients; and that it must arise from an unknown force, differing widely, at least in its effects, from ordinary chemical affinity.

Even therefore if we were to adopt the purely gratuitous assumption, that all other substances were compounded of carbon and hydrogen, we

should be driven to attribute the union to causes, which, so far as we know, have ceased to exist, as they never manifest their operation at the present day.

The only way indeed, in which I can conceive the formation of such bodies, is by supposing, that their component particles—which, on this hypothesis, may just as well be assumed to consist of one kind of matter, as of more—clustered together, when first formed, by the force of cohesive attraction, in various groups consisting of different numbers of the same, and that some of these groups, owing to mechanical conditions arising out of the arrangement of their component atoms, become indissolubly connected. These might constitute the bodies we regard as elements, since the difference in chemical properties which they present, might result from the mode of collocation of their atoms, agreeably to the principles laid down in my eighth chapter.

Thus hydrogen might consist of 10 of these primary atoms, oxygen of 80, carbon of 60, and so on.

Of course, according to this hypothesis, dimorphism would arise from a different arrangement, not of the ultimate particles, but of groups of them; the former being as immoveable, as the

properties arising out of their relative position are unchangeable.

But speculations of this kind, even if possessed of more intrinsic probability than they can lay claim to, must be carefully kept distinct from the facts of a science like chemistry, and from the deductions that flow legitimately from them; and it is on this point, that, even whilst indulging in a similar train of conjecture, I am disposed to join issue with my friend Mr. Lowe.

It is true, that in various parts of his work, the professor does make an appeal to certain natural phenomena, which lead him to imagine some of the supposed elements occasionally generated in various processes of animal and vegetable life; but into these I will not follow him, as I know of none, which do not admit of an obvious explanation in accordance with known principles; and shall merely observe, that all the arrangements of nature seem framed in reference to, and in accommodation with, the unalterableness of those bodies which we regard as elements.

So far from being able to elaborate the simple bodies which enter into its constitution, the vegetable has its growth immediately arrested, if there be a deficiency of phosphorus, of alkali, of lime, or of any other of the fixed constituents, com-

not enter into union either with it, or with the ultimate principles of which it consists.

Payen in France, who has written a very elaborate Memoir on Starch, in the *Annales des Sciences Naturelles*, represents it as composed of a number of concentric layers, surrounding a common axis, so as to form a globular or elliptical mass.

In its natural condition the whole mass of it is insoluble in cold water, but long continued boiling causes a change in its characters, rendering it gradually soluble in water of ordinary temperature. When this is brought about, it acquires the property of polarizing light to the right, and on account of this peculiarity has acquired the name of *dextrine*.

Now it seems to be ascertained, that the change from insoluble starch into soluble dextrine, which is brought about artificially by boiling, takes place also in nature spontaneously, occurring however in those parts of the plant only, in which it is requisite that the amylaceous matter, stored up for the purposes of its internal economy, should be rendered soluble in water, so as to be dissolved by the aqueous fluid of the sap, and carried up by the vessels or channels of circulation to those parts where a supply of it is wanted.

In both these cases, it is the opinion of Payen, suggested by the experiments of Pelouze and others, that the change is brought about, through the instrumentality of a minute portion of a substance found along with it, in the seeds of barley, oats, and probably of most other plants, *so soon as they begin to germinate*, and which, from its property of separating starch from other ingredients, as well as of altering its properties, is called *diastase*. It may be obtained by macerating malt in cold water, and then submitting it to a strong pressure. The liquid expressed contains the diastase, in union with other matters, separable from it however by the addition of alcohol, which precipitates it in the form of a white flocculent mass.

Thus diastase seems to be expressly intended by nature to render starch soluble, and thereby capable of being taken up by the sap, and it is interesting to find, that it exists in the potatoe, only in the tubers, and there just at the point of insertion of the young shoots, that is, exactly at the spot where they would be sent out; and consequently where it might be of use in rendering the starch soluble.

Thus it may be pointed out as a beautiful arrangement of nature, that the diastase is found in the

monly present in the soil from which it draws its nourishment ; whence arises the necessity for that beautiful system of provisions, by which nature restores the purity of the air vitiated by the respiration of animals, and disengages from the subsoil those materials, which it had stored up, in anticipation of the wants of the vegetable world, at periods long antecedent.

Of these truths, familiar no doubt to scientific agriculturists like Mr. Lowe, even the tyro in chemistry cannot be wholly unacquainted ; and I will therefore content myself with affirming, without fear of contradiction, that there is no one well authenticated fact, within the whole compass of chemistry, which countenances the idea of any of the so-called elementary bodies having ever undergone change, either by natural, or artificial agencies.

The argument therefore in favour of their transmutability, or of their derivation from some still simpler form of matter, is solely theoretical, resting upon the *à priori* improbability, that the Deity should have created so great a number of elements ; some of which are found in very minute quantities, and appear to minister to no useful purpose ; whilst others mutually approximate one to the other in their properties, so that we feel a

difficulty in acknowledging them as distinct and independent.

But does not any inference with respect to the compound nature of these bodies, grounded on such premises as the above, imply on our part an assumption of fuller acquaintance with the laws and the designs of creation, than we have any right to arrogate?

As well might the naturalist, observing a vast variety of distinct kinds of plants and animals, graduating by minute shades one into the other, and sometimes of very rare occurrence, or apparently not applicable to any useful purpose, conclude, in defiance of the principles established by observation, that the greater number were hybrids, produced by the intermixture of a few well marked fundamental species.

The original production of the inorganic bodies which serve to make up the fabric of the globe, is as much a mystery, as the first creation of the organic beings that exist upon its surface; both the one and the other seeming to lie beyond the scope of those natural laws of which we witness the operation, and to proceed, so far as we can perceive, from the immediate *fiat* of Omnipotence.

Why then may not that Being, who for his

own wise purposes called into existence a chain of living creatures, graduating one into another by the minutest shades, but yet so distinct, as to be incapable of intermingling, or of becoming confounded, have stamped likewise at the beginning of time upon different portions of brute matter, a set of distinct properties, calculated to be the germ of elements essentially different, but still in many cases nearly enough allied, to make them appear like the links of one common series.

CHAPTER XIV.

Inquiry as to whether the ancients possessed a knowledge of the doctrine of definite proportions—Whether such an insight into the laws of matter was likely to have belonged to them—Facts shewing that the Pythagoreans were somewhat acquainted with a system like the Copernican, although vaguely and imperfectly ; and with the doctrine of definite proportions, although obscured by their vague and mystical mode of stating the principle it involves—Physical science less indebted to the school of Pythagoras than to that of Democritus—testimony of lord Bacon to the merits of that philosopher.

In the preceding chapter I indulged in speculations, which perhaps may have exceeded those limits within which modern science has wisely circumscribed her domain ; whilst discussing the question, as to how far the bodies, which art has hitherto been unable to resolve into simple forms of matter, are to be regarded as in fact elementary.

In the present chapter, I purpose to take up an inquiry falling more within the compass of possible determination ; namely, as to the degree of knowledge which the ancients can be shewn to have possessed, of that doctrine of definite proportions, upon which, as we have seen, the Atomic Theory is mainly based.

If we choose to discuss this question on general grounds, with reference only to the abstract probability that they should have possessed such a knowledge, an appeal may be made to the opinions which many learned men have chosen to entertain, that a more profound knowledge of physics than any that has been transmitted to us by the ancients, belonged to the priesthood of Egypt and Chaldæa, and that the latter thus acquired that power over nature, which, under the disguise of magic, or other of the occult sciences, was employed by them, as one of the main instruments for augmenting their influence over the vulgar.

“ There are traces,” says bishop Berkeley*, “ of profound thought in the Platonic, Pythagorean, Egyptian, and Chaldaic philosophy. Men in those early days were not overlaid with languages and literature. Their minds seem to have been more exercised and less burdened than in later ages,

* On Tar Water, p. 141.

and, as so much nearer the beginning of the world, to have had the advantage of patriarchal lights, handed down through a few hands."

In corroboration of this view it might be contended, that tables for calculating the motions of the heavenly bodies, such as the places of the sun, moon, and planets, and rules for determining the phases of eclipses, have existed among the Brahmins, from a period more ancient than that, to which, with us, the history of the heroic ages is supposed to extend.

The system, on which these tables were constructed, implies, according to some, a considerable knowledge of geometry, arithmetic, and even of the theoretical part of astronomy; and, though at present in the hands of men, who follow its rules without understanding its principles, could hardly have been constructed originally without the existence of a body of science, the magnitude and extent of which may well excite our surprise.

Such was the opinion expressed by professor Playfair*, no mean judge of such matters, in consequence of an attentive study of the facts brought together on the subject by the learned

* On the astronomy of the Brahmins, in the Transactions of the Royal Society of Edinburgh, vol. ii. (1790.)

Bailly*; though others have discredited this inference, and have maintained, that a continued and patient observation of stated occurrences was all that would have been required, in order to obtain the data for calculating such events.

But abandoning the ground of abstract probability, it may be alleged, that the germs of those most important discoveries of modern times, viz. the Copernican system of the heavens, and the Daltonian theory of definite proportions, are to be found amongst the dogmas of Pythagoras; who is generally admitted to have derived whatever is most valuable in his philosophy, from the priesthood of Egypt; a country which he appears to have visited, shortly before the power of that body received its first shock, in consequence of the Persian invasion under Cambyzes.

With regard to the first of these, which is so far connected with our present subject, as it implies an amount of physical knowledge, hardly compatible, as some may think, with ignorance on other branches of philosophy, we have

* *Traité de l'Astronomie Indienne et Orientale*, par Bailly, Paris, 1787.

† *Νουμᾶς δὲ λέγεται καὶ τὸ τῆς Ἑστίας ἱερὸν ἐγκύκλιον περιβαλέσθαι, τῷ ἀσβέστῳ πυρὶ φρουρὰν. ἀπομμούμενος, οὐ τὸ*

the authority of Plutarch † and others, for affirming, that the revolution of the world round a central fire was taught by the Pythagoreans, who even were aware of its moving in an oblique circle, and that the form of the temple of Vesta at Rome, in the midst of which stood the sacred fire, was typical of this belief. Accordingly these philosophers, he assures us, maintained that our globe, far from being, according to the vulgar idea, the centre of the universe, held only an insignificant place among the members of one of innumerable planetary systems; and in this opinion, he says, that Plato, in his mature age, coincided.

It may however be replied, that although the

σχῆμα τῆς γῆς, ὡς Ἑστίας οὔσης, ἀλλὰ τοῦ σύμπαντος κόσμου, οὐ μέσον οἱ Πυθαγορικοὶ τὸ πῦρ ἰδρῦσθαι νομίζουσι, καὶ τοῦτο Ἑστίαν καλοῦσιν καὶ μονάδα· τὴν δὲ γῆν, οὐτ' ἀκίνητον, οὐτ' ἐν μέσῳ τῆς περιφορᾶς οὔσαν, ἀλλὰ κύκλῳ περὶ τὸ πῦρ αἰωρουμένην, οὔτε τῶν τιμιωτάτων οὐδὲν, οὔτε τῶν πρώτων τοῦ κόσμου μορίων ὑπάρχειν· ταῦτ' αὖ καὶ Πλάτωνα φασὶ πρεσβύτην γενόμενον διανενοῆσθαι, περὶ τῆς γῆς, ὡς ἐν ἐτέρᾳ χώρᾳ καθεστῶσης, τὴν δὲ μέσῃ καὶ κυριωτάτῃ ἐτέρῳ τινὶ κρείττονι προσήκουσαν. Plutarch. cap. 11. in Vita Numæ.

Φιλόλαος δὲ ὁ Πυθαγόρειος, γῆν κύκλῳ περιφέρεισθαι περὶ τὸ πῦρ, κατὰ κύκλου λοξοῦ, ὁμοιοτρόπως ἡλίῳ καὶ σελήῃ. Plutarch. de Plac. Phil. lib. iii. c. 13.

Πλάτων, Πυθαγόρας, Ἀριστοτέλης, εἶπον, διέρχεσθαι τὸν ἥλιον, περὶ τὴν λόξωσιν τοῦ ζωδιακοῦ κύκλου, δι' οὗ φέρεται λοξοπορῶν ὁ ἥλιος, καὶ κατὰ δορυφορίαν τῶν τροπικῶν κύκλων. Plutarch. de Plac. Phil. lib. ii. c. 23.

testimony of ancient writers proves that these philosophers had obtained a glimpse of the truth, it shews, at the same time, that they had but an incorrect and distorted view of it; for it is plain, from the quotations given below, that the sun and moon, as well as the earth, were supposed by them to revolve round this central fire; a sufficient indication that they were still far from apprehending the relation in which these bodies stand towards each other.

So correct is the remark, that Truth, though frequently touched, is rarely held fast in the dark; or, to adopt the theory of the opposite party, so imperfect and confused shortly becomes our recollection of her features, when the daylight, which disclosed them to us, is succeeded by a second night of ignorance.

With respect to the second great discovery alluded to, the doctrine of definite proportions, the language of the Pythagorean school is vague and mystical; and it would require more learning and patience than I can lay claim to, in order to disentangle the conflicting statements that have been made with regard to the doctrine of *numbers*, by which the laws of chemical combination may be conceived to have been shadowed out.

From some passages that might be quoted, it would seem, as if Pythagoras attributed to *numbers* a real existence, and considered them, as Plato did his *ideas*, the eternal archetypes of things; from others, that he meant to designate the *thing* numbered, confounding the *monad*, or that which is single, indivisible, and therefore perfect, with one, the most perfect of all numbers, and that to which all others are allied. Accordingly, the *monad* is used to signify the Deity, as being the first great Cause, one and the same, throughout all space, and in all time; whilst substance, or the world, is figured under the term *duad*, as being formed by the union of qualities, derived from the Deity himself, with amorphous matter.

In other cases the Founder of this school, or more probably his exoteric followers, attributed mysterious and magical powers to numbers, imagining the whole universe to be formed and kept together by virtue of them.

Yet it would seem, from some expressions that occasionally occur in the midst of this unintelligible rhapsody, that a more philosophical meaning was intended to be conveyed, and that the favoured disciples of this school were given to understand by the doctrine of numbers, some-

thing very analogous at least to the sublime discovery of modern date, that no combination can take place between the elements of matter, except in certain fixed numerical proportions.

Thus, according to Jamblichus*, number, as perceived by the understanding, (abstract number,) is that which subsisted in the Divine mind prior to all other things, by and out of which all bodies are brought into order, and linked together in an indissoluble series.

Number is represented by Hippasus†, one of the pupils of Pythagoras, as the first model employed in the creation; the rule according to which the Almighty determined to operate, with respect to the world he was about to call into existence.

By Philolaus, another of the same school, it is said to be the bond, sustaining by its power the permanent existence of every thing upon earth.

* Τὸ πρὸ πάντων ὑποστὰν ἐν θείῳ νῶ, ἀφ' οὗ, καὶ ἐξ οὗ, πάντα συντέτακται, καὶ μένει τάξιν ἄλυτον συνδιηριθμημένα. Jamblichus in Nicomachi Arithm. p. 11. editio Arnheim.

† Οἱ δὲ περὶ Ἰππασον ἀκουσματικοί, ἀριθμὸν εἶπον παράδειγμα πρῶτον κοσμοποιίας. Καὶ πάλιν κριτικὸν κοσμοουργοῦ θεοῦ ὄργανον.

Φιλόλαος δὲ φησιν, ἀριθμὸν εἶναι τῆς τῶν κοσμικῶν αἰωνίας διαμονῆς τὴν κρατιστεύουσαν, καὶ αὐτογενῆ συνοχήν. Id. *ibid*.

If these sentences are not sufficiently clear, we may perhaps interpret their meaning by the aid of a passage taken from another of the later interpreters of the Pythagorean philosophy; who seems to say, that the Founder of that school did not assert that things were produced, out of number, but according to, that is, in the proportion of number*; an expression which the Abbé Barthelemy†, who wrote several years before the modern doctrine of definite proportions was

* Καὶ συχνοὺς μὲν Ἑλλήνων πέπεισμαι νομίσαι, φάναι Πυθαγόραν, ἐξ ἀριθμοῦ πάντα φύεσθαι· οὗτος δὲ ὁ λόγος ἀπορίαν παρέχεται, πῶς ἂ μὴδὲ ἐστὶν ἐπινοεῖται γεννᾶν; ὁ δὲ οὐκ ἐξ ἀριθμοῦ, κατὰ δὲ ἀριθμὸν ἔλεγε πάντα γίγνεσθαι. Stobæi Eclogæ Physicæ.—A passage, which though very corrupt, may probably be thus translated:

“I am well aware that many of the Greeks contend, that Pythagoras said that every thing sprung out of number. But the real subject of dispute is, in what manner he imagined the invisible world, and things not generated, to have been produced (I do not say from number) but according to number.”

† We must here observe, that Pythagoras did not affirm that all things were formed by the virtue of numbers. If, in contempt of his express words, some of his disciples, imputing a real existence and secret virtue to numbers, have considered them as the constituent principles of the universe, they have so grossly neglected to unfold and explain their system, that we must be obliged to leave them to their impenetrable profundity. *Voyage of the younger Anacharsis.*

propounded, interpreted in the very sense in which I have here attempted to explain it.

This interpretation will likewise enable us to attach a meaning to the words of Aristotle, when he states, "that the Pythagoreans considered existing things to be an imitation of numbers*," that is to say, they supposed them to bear the same fixed and simple relation one to the other, which a series of whole numbers does to unity †; and, when we consider how much all sects of Grecian philosophers borrowed from Pythagoras, we need have the less scruple in tracing to him the doctrine so clearly laid down by the Platonizing Jew, Philo, or whoever was the author of the Book of Wisdom: who says expressly, *that God ordained all things in measure, number, and weight* ‡.

There seems, therefore, strong reason to believe, that something very like the theory of definite proportions was inculcated among the priests of

* *Μίμησιν εἶναι τὰ ὄντα τῶν ἀριθμῶν.* Arist. Metaph.

† As some moderns consider all other bodies to be multiples by a whole number of the lightest; a position, which, as we have seen, Dr. Thomson (regarding that body to be hydrogen) has attempted to establish by a series of elaborate experiments.

‡ *Πάντα μέτρον, καὶ ἀριθμῶ, καὶ σταθμῶ διέταξας.*

Egypt, from which Pythagoras derived his philosophy; as we have seen a similar doctrine to have prevailed even amongst the Hindoos.

It still, however, may admit of a question, whether the principle itself was gathered by the slow process of experiment and observation, or was received in consequence of its inherent probability, and some vague analogy with the laws of harmony in musical sounds; for if, on the one hand, it appear strange, that mere speculative inquiry should have led to the anticipation of such a physical truth; it is, on the other hand, improbable, that researches could have been carried on with the precision necessary to establish these conclusions, unless the people at large had attained to a degree of proficiency in the mechanical arts*, which seems incompatible with their

* It has been remarked, that all the genius which has been exerted in diving into the secrets of the material world, would have been in a great measure unavailing, had it not been for the discovery of four familiar substances, namely, platina, glass, cork, and India rubber (Liebig's Ch. Letters). Now the first of these was wholly unknown to the ancients; the second was a scarce, impure, and coarse representative of the transparent, ductile, and plastic material which glass becomes in the hands of the modern chemist; the third was rarely employed for its most important purpose, that of stopping vessels, amongst the Greeks and Romans (see Beckman,

general condition; with the monuments of that remote period that have come down to us; and with the ease with which they were overrun by the semi-barbarous hordes that successively invaded them.

We have had, even in the present age, the example of a poet*, who, without any practical knowledge of botany, framed in his closet a system with respect to the metamorphoses of the parts of plants, which was found wonderfully conformable to the conclusions afterwards deduced from an extensive survey of facts, by one of the first botanists of the age†; and there is therefore no absurdity in supposing, that the sages of Egypt may, by a similar happy generalization, have arrived at the perception of this simple doctrine of definite proportions, merely from a feeling of its conformity to the harmony of

History of Inventions); and the fourth was only brought into Europe towards the latter part of the last century. Dr. Priestley indeed mentions, in one of his works, India-rubber, as a recent introduction for the purpose of erasing pencil marks, and its employment for making tubes is of very recent date indeed.

* Goethe: see his *Essay on the Metamorphosis of Plants*, translated by De Gingens, Geneva, 1826.

† See Mons. Decandolle's various writings, especially his *Organographie*, and his *Théorie Élémentaire de la Botanique*.

creation, without ever ascending to it, as the moderns have done, by the gradual discovery of subordinate laws.

Nothing certainly can afford a more convincing proof of the soundness of a principle in science, than thus to find, that it had previously held a place amongst the speculations of a mind, which, like that of the German poet alluded to, may be said to *belong to that exalted region*, where the provinces of poetry and philosophy in a manner meet, and are blended together; but it would be unfair to adjudge to the anticipator of a great truth, the honour belonging to its discoverer; to adjudge to Goethe the meed due to Decandolle, or to Pythagoras that claimed by our countryman Dalton.

It is one thing, for a metaphysical mind dwelling continually upon abstract speculations, to entertain, as it were in the spirit of prophecy, views, that may be found afterwards to harmonize with the conclusions of inductive science, although but little intelligible until the latter have been promulgated; and another, to ascend by slow and successive steps to some grand general principle, which being followed through its various bearings, proves a guide in all succeeding ages to the discovery of unknown truths.

A French writer, however, M. Salvertè*, in a work of some ingenuity and research, though not always remarkable, it must be confessed, for sound judgment, has pointed out the various means employed of old by the Hierophant, to impose upon the imaginations, and subjugate the minds of the people; and has endeavoured to shew, that some of the artifices adopted for that purpose were such, as imply a knowledge of the physical sciences, similar, if not equal, to that which we are apt to set down as the exclusive privilege of the present age.

He attempts to get over the objection arising from the low condition of the people, by supposing this knowledge to have been confined to a few individuals, and therefore to have exerted no influence upon the character of the nation at large. It may indeed be admitted, that if the primary object of the initiated was power, not so much over nature, as over the minds of the people, whatsoever science they possessed would have been locked up within the sacred colleges; and that even there, the majority of its members would be made acquainted only with those secrets that were calculated to impose upon the multi-

* See Salvertè sur les Sciences occultes. Paris, 1829.

tude ; whilst the scientific principles on which they depended, were imparted only after a long period of probation, and to a limited number of the highest grade of adepts.

Where every thing depended upon secrecy, divulgement would be considered as the deepest of crimes ; and where all without the pale of the sacred colleges were regarded as profane and semi-barbarous, even the gratification of vanity would be sought, rather in mystifying and deluding the people, than in enlightening them.

Under such circumstances the destruction of the colleges by a foreign invader, and the slaughter or dispersion of their inmates, might have caused the almost total destruction of those treasures of knowledge, which the labours of successive generations had brought together ; for although the remnant that escaped into foreign lands would probably carry with them a knowledge of certain secrets, yet the chance would be much less of the few, that possessed the true key to such mysteries, surviving the general persecution of their order.

In this manner might the science they possessed gradually dwindle away, until little remained, save a collection of such processes as were best calculated to excite terror and surprise ; and

an assemblage of dogmas and observances, the meaning and intent of which were lost, or misunderstood in the mystical language in which they were conveyed.

Hence, though it may be true, that Pythagoras obtained from the Egyptians some glimpses of their learning, and though it is even possible, that he, and a few of his original disciples, may have been made acquainted with certain of the scientific truths which they possessed; yet it is very conceivable, that the Greeks in general should know but little more of the esoteric doctrines of this school, than has been reported to us in the works that have reached our time; so that they should value this philosophy, rather for its mystical tenets and ascetic observances, than for the truths that might be darkly shadowed out under a veil of oriental allegory.

Whatever degree of knowledge therefore may have been possessed by the Egyptian priesthood, or their disciple Pythagoras, one thing at least is certain, namely, that we are ourselves as little indebted to either for our actual information on such subjects, as we are to Roger Bacon for our method of manufacturing gunpowder, the ingredients of which he indicates in one of his works by an anagram, not difficult indeed to be deci-

phered at present, but conveying no meaning, before the nature of the compound itself had become known.

Neither can it be shewn, that either the Pythagorean philosophy itself, or those schools that imbibed its spirit and adopted its tenets, at all contributed to the discovery of the physical truths alluded to; it would rather seem, that by engaging the mind in speculations on subjects beyond the reach of the human intellect, and by inculcating habits of thinking altogether at variance with those which can avail us in the investigation of nature, they must have proved a fatal obstacle to the progress of such inquiries.

If any share in the discovery of the laws of combination, as at present established, can be assigned to the ancients, it is to the first propounders of the Atomic Theory, rather than to the authors of the Pythagorean System of Numbers, that the praise is due.

To Democritus indeed we owe the first outline of a scheme of philosophy, which appeals exclusively to sense and observation, instead of arbitrarily assumed principles*; which admits no

* "Atque hi omnes, (scilicet Empedocles, Anaxagoras, Democritus,)" says lord Bacon, "mentem rebus submiserrunt. At Plato mundum cogitationibus, Aristoteles vero

dogmas, but what are clearly apprehended, and may therefore be fairly grappled with ; and which, accordingly, after having had to struggle for centuries with prejudices derived, on the one hand, from the perverse use of its doctrines to inculcate atheistical opinions, and on the other, from the partiality felt by the learned for verbal and metaphysical subtleties, has at length been found to agree better than any of its rival systems with the results of experimental science.

To Democritus also we are indebted, not only for having made a more frequent appeal to observation than most of his cotemporaries, but also for having set the example of questioning nature by experiment ; a circumstance the more to his honour, as being so contrary to the genius of the age in which he lived.

“Accordingly,” as lord Bacon has observed, “the doctrine of atoms, from its going a step

etiam cogitationes verbis adjunxit ; vergentibus etiam tunc hominum studiis ad disputationes et sermones, et veritatis inquisitionem severiorem missam facientibus.” *De Principiis, secundum Fabulam Cupidinis et Cæli.*

These remarks of lord Bacon apply, it must be confessed, to a part of Aristotle’s works only ; but to this part the genius of the age had at that period given a prominence, which threw into the shade the better portions, and caused the impugnors of the scholastic systems to pass this too sweeping censure upon the character of his philosophy.

beyond the period in which it was advanced, was ridiculed by the vulgar, and severely handled in the disputations of the learned, notwithstanding the profound acquaintance with physical science, by which its author was allowed to be distinguished, and from which he acquired the character of a magician.

"However," he continues, "neither Aristotle with all his logical acuteness, (though like the Ottoman sultans he laboured to destroy all his brother philosophers, in order to rest undisputed master of the throne of science,) nor Plato with his sublime speculations, could effect the subversion of the doctrines of Democritus.

"Though the former systems were best suited for declaimers in the schools, the latter, cherished by those who wished to obtain a deeper insight into nature, appears to have kept its ground during the most flourishing periods of Roman literature, since Cicero always speaks of it with respect, and Juvenal, who, like poets in general, probably echoed the prevailing sentiment of the age in which he wrote, mentions its author as a noble exception to the general stupidity of his countrymen.

—cujus prudentia monstrat

Summos posse viros, et magna exempla duros,
Verecun in patria, crassoque sub aëre nasci."

“The destruction of this philosophy,” concludes lord Bacon, “is to be traced to Genseric and Attila, not to Plato and Aristotle. For when all human knowledge suffered shipwreck, the systems of the latter, being of a more flimsy and tumid texture, floated down to us; whilst the solid fabric of the corpuscular philosophy sunk to the bottom, and was forgotten*.”

* My readers will do well to consult the original in lord Bacon's Latin works, (“*De Principiis, &c.*” quoted in the preceding page,) as I have been obliged to drop in my translation much of that ingenious and beautiful metaphor, for which this illustrious writer is so distinguished.

ADDITIONAL NOTES.

Note to p. 33, on the Doctrine of Sufficient Reason.

Those who desire to see the bearing of this dogma upon the question as to the existence of atoms, may read the remarks on this subject in Euler's Letters to a German Princess, vol. II.; wherein will be found much discussion bearing on the question of the infinite divisibility of matter.

Additional Note to p. 34, on Boscovich's System.

"The easiest method of solving all the difficulties attending the subject of the subtlety of light, and of answering Mr. Euler's objections to its materiality, is to adopt the hypothesis of Mr. Boscovich, who supposes matter is not impenetrable, as before him it had been universally taken for granted; but that it consists of physical parts only, endued with powers of attraction and repulsion, taking place at different distances, that is, surrounded with various spheres of attraction and repulsion, in the same manner as solid matter is generally supposed to be." Priestley then goes on to develop Boscovich's views, and continues, "The most obvious difficulty, and indeed the only one that attends this hypothesis, as it supposes the mutual penetrability of matter, arises from the difficulty we meet with in attempting to force two bodies into the same place. But it is demonstrable, that the first obstruction arises from no actual contact of matter, but merely from powers of repulsion. This difficulty we can overcome; and having got within one sphere of repulsion, we fancy that we are now impeded by the solid body itself.

But the very same is the apprehension of the generality of mankind with respect to the first obstruction. Why, therefore, may not the next resistance be only another sphere of repulsion, which may only require a greater force to overcome it, without disordering the arrangement of the constituent particles; but which may be overcome by a body moving with the amazing velocity of light?

“This scheme of the *mutual penetration of matter*, first occurred to Mr. Michell on reading Baxter on the Immateriality of the Soul. He found that this author’s idea of matter was, that it consisted, as it were, of bricks cemented together by an immaterial matter.

“These bricks, if he could be consistent in his reasoning, were again composed of less bricks, cemented likewise by an immaterial mortar, and so on *ad infinitum*. This putting Mr. Michell upon the consideration of the appearances of nature, he began to perceive that the bricks were so covered with this immaterial mortar, that, if they had no existence at all, it could not possibly be perceived, every effect being produced, at least in nine instances in ten certainly, and probably in the tenth also, by this immaterial, spiritual, and penetrable mortar.

“Instead, therefore, of placing the world upon the giant, the giant upon the tortoise, and the tortoise upon he knew not what, he placed the world at once upon itself; and finding it still necessary, in order to solve the appearances of nature, to admit of extended and penetrable immaterial substance, if he maintained the impenetrability of matter; and observing further, that all we perceive by contact, &c. is this penetrable immaterial substance, and not the impenetrable one; he began to think that he might as well admit of penetrable material, as penetrable immaterial substance; especially as we know nothing more of the nature of substance than that it is something which supports properties: which properties may be whatever we please, provided they

be not inconsistent with each other, that is, do not imply the absence of each other.

"This by no means seemed to be the case, in supposing two substances to be in the same place at the same time, without excluding each other; the objection to which is only derived from the resistance we meet with to the touch, and is a prejudice that has taken its rise from that circumstance, and is not unlike the prejudice against the antipodes, derived from the constant experience of bodies falling, as we account it, downwards," &c. &c. *Priestley on Matter and Spirit*, p. 19.

Note to chapter I. p. 38.

Mr. Davies Gilbert on the Hypothesis of Boscovich.

On Boscovich's theory, I was favoured, soon after the publication of my *Essay on the Atomic Theory*, with a letter from Mr. Davies Gilbert, the following extract from which, whatever opinion may be formed of its intrinsic merits, will, I doubt not, be received with a feeling of interest, as emanating from one, whose decease the world of science and of letters has so much reason to deplore.

On the character and talents of that distinguished philosopher it is not my purpose here to dilate; but as a member of that University, towards which from the first commencement of his academical career he ever evinced so warm an attachment, and which has so many motives for regarding his memory with gratitude and affection, I ought not to withhold my individual testimony to the depth and extent of his acquirements—to the disinterested love of truth, which alone led him to amass such various stores of information—to his readiness in imparting them freely to others—and to the simplicity of demeanour, and easy courtesy of manner, which rendered his society no less agreeable than instructive.

Much indeed as he may have advanced knowledge by

those contributions to its various branches which bear his name, it must be allowed that he served its interests still more effectually, by the assistance he afforded to others in the prosecution of similar objects, and by the zeal and discernment he displayed in seeking out and enlisting in its cause talents, which, but for his exertions, might have continued in obscurity, as his early patronage of the illustrious Davy sufficiently indicates.

"Undoubtedly," says Mr. Gilbert, "we are utterly unacquainted with the *ὑπόστασις*, which sustains the qualities usually supposed to indicate matter, and we are as entirely unacquainted with that which sustains the qualities indicative of mind; but the striking inconsistencies involved in associating together the ideas of extension and of atoms have so embarrassed philosophers, that every expedient has been had recourse to for resolving the difficulties.

"The most obvious mode, that of reducing the atoms to extremely small dimensions, utterly fails, for a particle extended to the millionth of an inch must be considered as capable of division as the earth itself.

"At length Boscovich fell upon the expedient of denying the *ὑπόστασις* altogether.

"Qualities are by him supposed to accumulate round points of space, attractions and repulsions succeeding each other.

"If these principles be admitted, there can be no such thing as impenetrability. For as attraction and repulsion are merely potential, until they pass into energy through the medium of time, or as the effect produced by either is as the force drawn into the time through which it acts, it follows, that if the time be reduced without limit, by giving to the force an infinite velocity, one set of points would pass through another set, without producing the least sensible derangement.

"As an illustration. A ball, shot from a gun, will pass through a board carrying the piece before it, but with such

rapidity that the cohesive attraction of this piece to the rest of the board has not time to act.

“Boscovich also conjectures, that the ultimate sphere of qualities may be one of attraction, extending into infinite space, and there constituting gravity.

“There is however still another power inherent in matter, which in my opinion is quite as extraordinary as universal gravity itself.

“I do not mean the quality of passiveness imputed by the ancients to matter, but rather the active power of maintaining itself in the condition whether of rest or motion in which it is placed, which we mean when we speak of the ‘Power of Inertia,’ a word as good as any other as a mere name, but etymologically quite incorrect.

“In consequence of this quality, matter maintains to all eternity the state of motion in which it has been placed by the last power, acting through time, to which it had been subjected.

“This power of maintenance is a quality in all respects distinct from that of attraction or of repulsion, and although, in the profound adoration of the Divinity, I can ascribe to Omnipotence anything not absolutely inconsistent with something else, yet nothing certainly short of infinite power could, as I think, be sufficient for adding inertia, or the quality of maintenance, to those abstract points of Boscovich.

“If we use the word matter as synonymous with substance, or *ύπόστασις*, then gravity and inertia will be *super-added* qualities, and from this assumption will arise one of the most truly astonishing coincidences in nature, namely, that these two qualities always preserve the same invariable proportion one to the other, supposing gravity to act at a given distance, although we are unable to discover the slightest link of connexion between them.

“If Venus, for example, moving in a circle, had either the velocity of her motion suddenly doubled, or the action

of gravity reduced to a quarter, or her power of maintenance (her inertia) augmented fourfold, her orbit would change to a parabola.

"We have not however anything practically to do with the ultimate particles or atoms of matter.

"The great discovery of Dalton, one greater indeed than any made since Sir Isaac Newton discovered gravity and inertia, has proved that the proximate particles exist *ἐν μερῶν*, καὶ ἀριθμῶν, καὶ σταθμῶν, and our faculties will not, I believe, enable us to go further."

Note to p. 73. chapter II.

Comments by the late Dr. Prout, on various points developed in this chapter, with respect to the combinations between the Atoms of Matter.

When the first edition of this work had gone through the press, its contents were submitted to my lamented friend Dr. Prout, who, after perusing them, favoured me with the following remarks; which I am still anxious to retain, not only as they may serve to explain more fully some peculiar views of his to which I have alluded; but also as they proceed from a philosopher of such high eminence, whose memory will be always dear to me, from recollections of the long and familiar intercourse which I had the advantage and pleasure of enjoying; and whose favourable opinion of the first imperfect sketch of the present Treatise furnishes me with my best apology, for offering it again to the public in the present more developed, and, as I trust, improved form.

"Sackville-street, Sept. 12, 1831.

"DEAR SIR,

"I was much gratified by a perusal of your Essay on the Atomic Theory: there are, however, a few points in which I am more immediately concerned, apparently requiring some remarks, and which I shall consider in the order they occur.

"In page 39 you observe, 'I believe, indeed, that I shall not be misrepresenting Dr. Prout's opinions, if I remark, that in the paper alluded to he seems to have noticed the relation between the numbers . . . chiefly as a presumption in favour of the idea of their being possibly compounded of oxygen and hydrogen, of which they appear to be multiples.' The original opinion to which I was led by the observations of others, and innumerable experiments (never published) of my own, was, that the combining or atomic weights of bodies bear certain simple relations to one another, frequently by multiple, and consequently that many of them must necessarily be multiples of some one unit; but as the atom of hydrogen, the lowest body known, is frequently subdivided when in combination with oxygen, &c. there seems to be no reason why bodies still lower in the scale than hydrogen (similarly however related to one another, as well as to those above hydrogen) may not exist, of which other bodies may be multiples, without being actually multiples of the intermediate hydrogen. Such was my *opinion* in general terms; my *speculations*, I confess, went further, and were indeed pretty much as you have stated them to be.

"Page 44 and 62, you remark, with respect to the general notion of atomic series rather than units, 'that you are not aware of any facts which do not equally admit of being referred to the theory more commonly adopted, and that you do not see the absurdity of supposing that in organic compounds, where the terms of the series are, as is the case of water, represented as $3 : 6 : 9 : 12$, &c., the true relations may not be as $9 : 18 : 27 : 36$ corresponding to $1 : 2 : 3 : 4$ atoms of water;' and again, 'that you do not see that the theory of Dalton holds out any stronger temptation to fraud than the laws substituted for it by me.'

"To reply to the first of these remarks as it ought to be replied to, and indeed as I perhaps *could* reply to it, would lead me far beyond my present purpose; I shall therefore

merely observe, that by adhering to a single term (with reference to which I am quite aware all others may be expressed) great difficulties often occur, and the real (often very simple) compositions of bodies are so masked and *apparently* misrepresented, that they cannot without difficulty be recognised in some instances.

"With respect to the second objection, I may remark, that my notions were not proposed with the expectation that they would make honest men of knaves: though it may be worth while to observe, that by diminishing the number, the *amount* of error is likely to be diminished.

"The series given for water, I wish it to be observed, applies to its combination with carbon, and perhaps some other bodies; but in uniting with bodies having different combining series, the aqueous series itself *may* become modified or different; and hereby hangs, if I am not much mistaken, a very curious tale, which I hope some one will tell ere long better than I am able to do.

"At page 62, you speak of the '*censures**' I have cast on the atomic theory.' Now this is a much stronger term than I am willing to allow. There is no one can possibly have greater respect for Mr. Dalton, and all that he has done, than myself; and I am a firm believer in his principles *as far as they go*, because I believe them to be founded in truth. What I meant to say was, that they do not contain *all* the truth, and that consequently in *their present state* they are inadequate to explain the operations of nature. It is however my opinion, that the system of Dalton, even in its present state, on account of its great simplicity and convenience, never will nor ought to be superseded; and that consequently it will continue to be employed for these reasons, just as the Linnean system continues to be employed for

* I have omitted this passage in the present edition, feeling that the term "*censures*" was ill-chosen, and conveyed a meaning which did not apply to the case in question.

very similar reasons by botanists; and here I may remark, by the by, that I referred to botany in my Lectures rather for the sake of illustration, than from any close analogy between this science and chemistry, which I was well aware did not exist.

"Pages 68 et seq. you speak of the doctrines of *isomorphism* and *isomerism*; and though I do not observe that you allude to any thing that I have said on the subject, I am anxious to make a few remarks on a passage in my Lectures, which from the terms employed may be liable to be misunderstood. I have said that the continental chemists have succeeded in establishing the curious and important doctrines of isomorphism and isomerism—doctrines totally inexplicable upon the principles of Dalton and Berzelius, but which seem to me to flow necessarily in conjunction with some others from the principles which I have long considered as regulating the union of bodies in nature.

"In the Lectures as delivered, these doctrines were very briefly explained, and I wish here to remark, that I mean nothing more by the above, than that the doctrines in the abstract, or generally speaking, are established, which I believe to be the case; as for the details, I always considered many of them exceedingly unsatisfactory. So long ago as 1815, I was led to infer, that relation in *weight* might indicate a relation also in *size* among the atoms of bodies*; and that many of those striking and curious analogies in property, form, &c. which I thought I observed among bodies atomically related, might depend upon one or other of these circumstances. But, as soon after this period I relinquished chemistry in general, I thought little more of the matter, till the doctrines of Mitscherlich were announced. I merely mention this, but without

* See Annals of Philosophy, VII. 113. where the general principles on which this notion was founded are briefly stated with another view, viz. that of explaining the relation between the doctrine of atoms and of volumes.

advancing the shadow of a claim to the honour of the discovery of isomorphism, which, as far as I know, is entirely due to the eminent philosopher above mentioned. With respect to *isomerism*, in my Lectures as originally written, I alluded to three varieties or modifications of this principle as existing in bodies—one in which the same elements are differently arranged; a second, in which the arrangement (still crystalline) is different, but which difference depends upon the presence of minute quantities of foreign bodies; and a third, which I have provisionally termed *merorganization*, in which the general arrangement, besides being peculiar, may be also supposed to be subject to or influenced by the same causes which produce the peculiar arrangements in one or both the other two varieties. All these varieties, I believe, are inexplicable upon the principles of Dalton *as they at present stand*, but on these principles *as they may be extended*, I have strong hopes that one day or other the two first varieties at least will be explained.

“You allude to the speculations of M. Decandolle on the forms of plants, and I will amuse you with a speculation of mine on the same subject, viz. that these forms are somehow or other connected with the oxygen series 2 : 4 : 6 : 8, &c. and the isobaric series of carbon and water 3 : 6 : 9 : 12, &c. I think I could bring forward many curious circumstances illustrative of this opinion.

“I remain, dear sir, yours very truly,

“W. PROUT.”

“P. S. I approve of your ingenious observations on mineral waters*, which, I think, throw considerable light on their constitution. My professional pursuits keep me away so much from chemical details, that it is very possible I may have committed some errors in the preceding observations. If so, I beg you will correct them. W. P.”

* These remarks of mine will be included in the Additional Notes.

Note to p. 110, chapter III.

Remarks by Dr. Dalton on certain passages in the text relative to the laws of definite proportions.

The same motive that induced me to solicit the preceding remarks from Dr. Prout, namely, a wish to put forth no statements of a doubtful or debatable kind, unaccompanied by the objections that might be raised against them, led to my submitting the pages of my original work, when printed, likewise to Dr. Dalton, who in consequence favoured me with the following comments on certain passages contained in it.

The modesty of the author indeed led him to represent these notes of his as scarcely worth publication in their present form ; but I should be doing an injustice to my readers by withholding them, even supposing a more critical eye should detect any inaccuracies, which have escaped me in their perusal.

Having, indeed, been permitted by Dr. Dalton to alter or correct them at pleasure, it may be considered that I am in some degree responsible for their publication ; but whatever blame may attach to myself for having refrained from exercising the discretionary power confided to me, the work at least will gain in value, by becoming the vehicle for recording the views of the illustrious Father of the Atomic Theory, at a period when they had been matured by long reflection on his part, and by the discussion they had met with from the general body of scientific men, to which they had for several years previously been submitted.

“ RESPECTED FRIEND,

“ I have occasionally turned my attention to your Essay ever since I received it, and shall now communicate to you a few observations that have struck me. On the 1st chapter

I make no remark, further than that it contains matter of interesting information. The head of the 2d chapter announces that * 'every substance enters into combination in certain fixed proportions, of which the larger are multiples of the smallest.' According to my views, this is not sufficiently definite: take, for instance, the case of azote and oxygen; here a given weight of azote unites to 1, 2, 3, 4, and 5 proportions of oxygen, which agrees with the observation; but if we begin with the smallest proportion of azote which combines with oxygen, and proceed upwards, we find

84 Azote	+ 240 Oxygen,	Nitric acid.
105 —	+ 240 —	Nitrous acid.
140 —	+ 240 —	Subnitrous acid.
210 —	+ 240 —	Nitrous gas.
420 —	+ 240 —	Nitrous oxide.

Here we see no multiples of the smallest combining quantity of azote, but the last number; and further, if these numbers are correct, the combining number or atom for oxygen must be 240, and that for azote 84; otherwise we must introduce fractions to express some of the ratios. This one case sufficiently shews that when two bodies A and B combine, we must collect the facts, and then examine whether it is A or B that combines in multiple proportions. Nor is this all: I observe that you conform to the general

* This passage occurs only in the table of contents, and is, I admit, not worded with sufficient precision. It will be perceived that the numbers given by Dr. Dalton to represent the combining quantities of azote, are multiples not of the atomic weight given of that body in this Essay, which is 14, but of half of it. Thus:

$$\begin{aligned}
 7 \times 12 &= 84 \\
 7 \times 15 &= 105 \\
 7 \times 20 &= 140 \\
 7 \times 30 &= 210 \\
 7 \times 60 &= 420
 \end{aligned}$$

arrangement of British chemists of the day, which was first introduced by Berzelius about 1810 (I believe), and was too hastily adopted by Drs. Wollaston, Thomson, &c. and which Berzelius has been the first to relinquish. I mean

14	Azote +	8	Oxygen,	Nitrous oxide.
14	— +	16	—	Nitrous gas.
14	— +	24	—	Sub or per-nitrous acid.
14	— +	32	—	Nitrous acid.
14	— +	40	—	Nitric acid.

Now all this *may* be correct; but why are we to conclude that 14 is the proper representative of an atom of azote? I do not think it is. I adopted, 28 years since, my atomic view of the combinations of azote and oxygen (Memoirs, vol. I. 1805), the principle of which I still retain, and in which Berzelius now agrees with me, as you will find by his late table: according to this, the atomic weights will be

000	—	14	Azote +	8	Oxygen,	Nitrous acid.
00	—	7	— +	8	—	Nitrous gas.
000 00	—	14	— +	24	—	Per- or sub-nitrous acid.
000	—	7	— +	16	—	Nitrous acid.
000 0 000	—	14	— +	40	—	Nitric acid.

“There are many considerations that suggest that the atom of nitrous gas is the most simple of the combinations of azote and oxygen: 1st, its specific gravity; 2d, its readily combining with oxygen, and sometimes also with azote; 3d, its easy resolution by electricity into azote and oxygen; the latter of which, by combination, instantly forms nitrous acid; 4th, the formation of nitrous acid from a mixture of azote and oxygen when electrified, as was done by Mr. Cavendish, in which operation nitrous gas is first formed, and then nitrous acid instantly follows. But I must not enlarge on this head.

" Page 37. instead of, I should have preferred placing

Hydr. 1	Carbon 3	Marsh Gas	Hydr. 2	Carb. 6
— 1	— 6	Olephant Gas	— 1	— 6*
— 1	— 18	Nepthalino	— 1	— 12

" Page 56. '3 combinations of A and B, whose atomic weights are represented by the numbers 8 and 14.' In my opinion the presumption would be, that they were composed

<i>not of</i>	<i>but of</i>
A 8, B 14	A 16, B 14 = 2 A + 1 B†
A 8, B 28	A 8, B 14 = 1 A + 1 B
A 8, B 42	A 8, B 28 = 1 A + 2 B,

unless some reason could be assigned to the contrary from the properties of the compounds. All affinities must be mutual, and 1 atom of A has only the same claim to 2 of B, that 1 of B has for 2 of A.

" Whilst upon this subject, namely, the taking a view of all the ways in which the several combinations of 2 elements may be explained, I will take the liberty of assuming a case: Suppose I find that in 2 elements, A and B, there are the following combinations, namely:

Grains. Grains.

A 2 + B 2

A 2 + B 3

A 2 + B 6

A 2 + B 12

A 2 + B 18

and that these 5 are all the combinations I can find experimentally. Now should I be so unlucky as to take the 1st for a binary compound, and consider the atoms of A and B

* It will be seen that I have adopted this alteration in the present edition, page 68.

† The difference between us may be shewn thus:

My way.	Your way.
○○○	○○
○○	○○○
○○○	○○○
	○

as of equal weights, I should be puzzled to account for the rest of the combinations; the 2d would be 3 atoms of B with 2 of A; the 3d would be 1 atom of A with 3 of B; the 4th, 1 atom of A with 6 of B: and the 5th, 1 atom of A with 9 of B. But I might ask, why should they not be combinations of the intermediate numbers?

"A much more probable supposition would be, to take as the atomic weights, A 2 and B 6; then the 3d would be a binary combination; the 2d and 4th ternary; and the 1st and 5th quaternary; so that there would be no occasion to have more than 4 atoms in any group, and we should have no deficiencies in the combinations.

"Page 57. The numbers denoting the weights of the atoms in this table are not all, I fear, sufficiently correct. I do not know where we are to look for the exact sp. gr. of hydrogen gas, and if this be not correctly known, then all the atomic weights will be wrong, and the doctrine of volumes be in jeopardy.

"Dr. Wollaston's Lecture in 1813 is an expansion of the ideas I published in 1808. (Chemistry, vol. I. p. 210.) When he mentioned those ideas to me in conversation, (I think in 1810,) he could scarcely credit that I had entertained and published the same, until he brought my book out of his library, and I shewed him the page. He had probably seen it before, but had forgotten it.

"With regard to the Tables at the end, there are several errors, in my opinion, as to the weights both of the simple and compound atoms; but as this is debatable ground, I shall not enter upon it at large. I may observe that my present view of *alum* coincides with that of Berzelius, and was deduced without the knowledge of his. I cannot agree with him in regard to phosphorus, arsenic, minium, &c.; but upon the whole I agree with him as well or better than with others.

"I remain, yours truly,

"JOHN DALTON."

Note to chapter VII. p. 202.

On the Invention of the Theory of Chemical Types.

In stating, that M. Laurent suggested the doctrine of chemical types, which Dumas has been so instrumental in bringing forward, and recommending to the notice of chemists, I have been guided by the fact, that Laurent's Memoir in the *Annales de Chimie*, entitled, "*Théorie des Combinaisons Organiques*," bears the date of 1836, and his Thesis, that of 1837; in both which the fundamental idea of this mode of viewing the constitution of bodies seems to be entertained: whereas Dumas' first Memoir on Chemical Types was printed in the volume of the same periodical for 1840.

The respective claims of these two chemists to the honour of having originated this theory, have given rise to rather an acrimonious discussion in the *Comptes Rendus* of the French Academy for 1840; from a superficial glance over which, I infer, that some glimpses of the doctrine in question had flashed across the minds of several chemists at nearly the same period of time; and that we are indebted, not only to Laurent and Dumas, but likewise to Regnault, Persoz, and others, for that assemblage of new facts, which have since given it stability, and erected it into one of the leading principles of the science.

But, whatever pretensions Laurent may set up to priority in suggesting these views as to the nature of organic compounds, it is certain, that we are indebted to Dumas for placing them before us in a luminous and philosophical form, supported by an overpowering array of facts, many of the most conclusive of which are derived from his own original investigations.

It is not for me to mete out the exact amount of credit, due to these several chemists, for the share they have had in establishing the theory in question; but I must correct

one mistake into which I have fallen in p. 195, where Laurent has ascribed to him the invention of an ingenious mode by which the replacement of one or more atoms of any element by another is denoted; namely, that of introducing into the final syllable of the name, one or other of the five vowels of the alphabet in their natural order of sequence.

This, it should seem, was first suggested by Dumas in 1834, in his memoir on the essential oil of cinnamon; in which the name of *chlorocinnose* was proposed for a compound, having four atoms of chlorine substituted for four of hydrogen.

Note to chapter VIII. p. 256.

On Dumas' Theory of Organic Radicals, and on the reasons for preferring the theory respecting the same which was proposed by Liebig; also on Gerhardt's Classification of Organic Compounds.

Liebig has adduced several reasons for regarding ether as an *oxide*, and wine alcohol as an hydrate of ether, in which case its radical must be $C_4 H_5$; and the same applies to other bodies similarly constituted, such as the methylic ether, and its corresponding alcohol, viz. wood spirit.

In the first place, sulphuric acid cannot abstract water from ether, as from its strong affinity for that fluid, it ought to do, if it were present.

Again, ether acts to all intents as a *base*, neutralising the strongest acids, and possessing a saturating power exactly equivalent to that of the oxygen which, according to that hypothesis, is present in it, the radical $C_4 H_5$ always remaining constant.

Alcohol yields its oxygen to the hydrogen of muriatic acid, and unites with the chlorine, thus forming muriatic ether $C_4 H_5 Cl$, water being at the same time eliminated.

Now this may be understood, if we suppose alcohol to be

formed of $C_4 H_5 O + Aq$, $H Cl$ being added; but not if we suppose it formed of $C_4 H_4 + Aq_2$; because we must then assume that muriatic acid combines directly with $C_4 H_4$, whereas no union takes place between olefiant gas $C_4 H_4$, and muriatic acid, when these bodies are brought together.

The production of aldehyde $C_4 H_3 O + Aq$ from alcohol $C_4 H_5 O + Aq$, by the abstraction of H_2 , through the dehydrogenating influence of chlorine or oxygen; and the production of acetic acid from the latter, by the addition of an amount of oxygen equal to that of the hydrogen before abstracted, may both be readily explained, according to the received laws of combination, if we regard ether as an oxide; for then we may suppose H_2 removed from the base in the first instance, and O_2 added in the second.

But according to Dumas, aldehyde would be an oxide of olefiant gas, represented by the formula $C_4 H_4 + O_2$. Now when this substance passes into chloral ($C_4 Cl_3 + O_2$), chlorine would be substituted for three atoms of hydrogen, but not for the fourth atom, for which anomaly no explanation has been proposed.

Upon the whole the preponderance of opinion in this country is decidedly in favour of the theory of ethers, which Berzelius first suggested, and which Liebig has supported; although in France the opposite view seems to be still* maintained by Dumas, as well as by Laurent, and by Gerhardt.

I must refer to the work of the latter chemist entitled, "*Précis de Chimie Organique*," for a classification of organic bodies according to this principle, conceiving that it well deserves to be studied by the more advanced chemist. Gerhardt there divides organic compounds into 26 families, according to the number of atoms of carbon supposed to

* I allude to the period of the publication of the 7th volume of his *Traité de Chimie*—namely 1844.

concur with other elements in the formation of the compound atom of the substance represented. Thus, at the bottom of the scale, we find bodies, with 1 atom of carbon to 1 or more atoms of the other elements; and at the top, bodies with 26 atoms so combined.

These families are subdivided into a number of genera, distinguished, according as they consist of carbon and hydrogen wholly, or as they contain in addition 1 or more atoms of oxygen*.

Bodies then, in which the atoms of carbon and hydrogen are equal, whatever may be the number united together, are designated by the symbol R.

If in addition to R, they contain

- | | |
|------------------------------|------------------|
| 1 of oxygen, they are marked | R O |
| 2 ————— | R O ₂ |
| 3 ————— | R O ₃ |

Now each of these genera may present a series of distinct species, according as the hydrocarbon, which constitutes the basis of the family group, stands alone, is united to 1 additional atom of hydrogen, or is shorn of 1 or more atoms of the hydrogen which enters into the constitution of its base.

Let us take, for instance, the family at the head of the

* In order to prevent confusion, I have taken the liberty of altering Gerhardt's notation, so far as to make it accord with that employed in my own, and in most other works, halving the numbers which he sets down for the atoms of hydrogen; and likewise regarding the composition of wood spirit as C₂ H₄ O₂, instead of C H₂ O; of formic acid C₂ H₂ O₄, instead of C H O₂; of alcohol C₄ H₆ O₂, instead of C₂ H₃ O, and so of the rest; my object being, not to bring before my readers Gerhardt's peculiar views, but simply to convey some notion of his method of classification.

scale, the essential character of which is the existence in it of an hydrocarbon, consisting of C 26 H 26.

Now the several genera of this family may be conceived to include the following distinct species, although actually no examples of the greater number are as yet known to us.

Besides the species containing the radical, with its full complement of atoms of hydrogen, there may be also one with the same number +1 of hydrogen; and inasmuch as they are 26 atoms of hydrogen belonging to the base, any number of which might from analogy be supposed removable, as many more species may be conceived, as there exist atoms of base.

These may be distinguished as follows:

R; R+1; R-1; R-2, &c.

On the other hand, the genera of the family which stands at the bottom of the scale could only admit, in addition to species R, and R+H, of as many, as were equivalent to the number of atoms of hydrogen which their radical contained.

Supposing then we were to consider with Gerhardt, that there exists a radical consisting of CH; and were to adopt his formula for wood spirit and for formic acid, the following would represent the genera and species of this, the lowest family in his scale of organic compounds.

Symbol of the family	Genera	Species.		
		R+1	R	R-1
R 1 (viz. CH)	R	CH ₂		
	RO	marsh gas CH ₂ O		CO
	RO ₂	wood spirit		carbonic oxide
	&c.		CH ₁ H ₁ O ₂ formic acid	CO ₂ carbonic acid

Now Gerhardt designates by the term *homologous*, those bodies, which occupy the same relative position in different parts of the scale, and which in consequence possess similar chemical properties, as well as certain analogies one to the other in point of composition.

The following are examples :

<i>Homologous bodies.</i>	<i>Homologous bodies.</i>	<i>Homologous bodies.</i>
C ₂ H ₄ O ₂ , wood spirit	C ₂ H ₂ O ₄ , formic acid	C ₂ H ₃ Cl, hydrochlorate of methylene
C ₄ H ₆ O ₂ , wine spirit	C ₄ H ₄ O ₄ , acetic acid	C ₄ H ₅ Cl, hydrochlorate of etherene
C ₁₀ H ₁₂ O ₂ , fusel oil.	C ₁₀ H ₁₀ O ₄ , valerianic acid	C ₁₀ H ₁₁ Cl, hydrochlorate of amilene
C ₃₂ H ₃₄ O ₂ , ethal	C ₃₂ H ₃₂ O ₄ , ethalic acid	C ₃₂ H ₃₃ Cl, hydrochlorate of cetene

Nevertheless, the actual discovery of bodies, possessing the composition ascribed to three, and even to four of the supposed radicals (see p. 249), gives a certain preponderance to the arguments in favour of the view which has been adopted in the body of this work; and the only thing now required to substantiate its truth, seems to be, the direct synthesis of some of the compounds related to each, through the union of these supposed radicals with the elements which analysis proves their derivatives to contain.

Until this be effected, the advocates of the rival theory may continue to maintain, with Gerhardt and his party, that Dr. Frankland's methyle C_2H_3 should be considered as an homologue to marsh gas; viz.*

Marsh gas $C H + H$

Methyle . . $2 C H + H$.

and so with the rest.

Appendix to the preceding note.

Since the preceding note was sent to the press, I have perused a Memoir by Dr. Hoffmann, published in the number of the Journal of the Chemical Society for the present month (July 1850), which confirms me in the belief I had expressed in the text, p. 250, that the true relation which the new bodies discovered by Dr. Frankland and Kolbe bear to the alcohol and ether series, is a point which remains for discussion.

Dr. Hoffmann has therein pointed out, that the view taken by Gerhardt, alluded to above, is still tenable; and that the various compounds noticed above may be conceived to have been built up somewhat in the following manner:

Methylene

* See Comptes Rendus de Chémie par Laurent et Gerhardt, Jan. 1850.

Methylene, of Dumas	... (C ₂ H ₂) + H ₂ = Marsh gas (C ₂ H ₄)
Marsh Gas	..... (C ₂ H ₄) + 2 Carbonic acid (C ₂ O ₄) = Acetic acid (C ₄ H ₄ O ₄)
_____	... (C ₂ H ₄) - H + O = Methylic ether (C ₂ H ₃ O) + Aq. = Wood-alcohol (C ₂ H ₄ O ₂)
Olefiant gas.....	(C ₄ H ₄) + H ₂ = Hypothetical radical called Acetene (C ₄ H ₆)
Acetene	..... (C ₄ H ₆) + 2 Carbonic acid (C ₂ O ₄) = Metacetic acid (C ₆ H ₆ O ₄)
_____	..... (C ₄ H ₆) - H + O = Sulphuric ether (C ₄ H ₅ O + Aq. = Wine alcohol (C ₄ H ₆ C ₂)
Quadrocarburet of Faraday (C ₈ H ₈) + H ₂	= Hypothetical radical called Valerene or Butene (C ₈ H ₁₀)
Valerene or Butene	..... (C ₈ H ₁₀) + 2 Carbonic acid (C ₂ O ₄) = Valerianic acid.
_____	..... (C ₈ H ₁₀) - H + O = Ether undiscovered (C ₈ H ₉ O)

Now it will be perceived, that the hypothetical radicals, acetene, and butene, or the homologues of marsh gas, are exact multiples by 2 of methyle and ethyle. Dr. Hoffmann contends, that the boiling point of these latter bodies agrees better with analogy, if, in accordance with Gerhardt's views, we double their formulæ, than if we assume them to be compounds respectively of $C_2 H_3$ and $C_4 H_5$.

The Memoir is well deserving the attention of chemists, and, it is hoped, will lead to further researches, by which the question at issue may be finally set at rest.

The same number of the Journal announces the discovery by Captain Reynolds of another homologue of olefiant gas, namely propylene $C_6 H_6$, so that we may now reckon no less than 12 different isomeric bodies, all of them multiples of the methylene of Dumas, $C_2 H_2$, noticed in p. 185, but there erroneously stated to be an hypothetical substance; for it appears from the Memoir by Dumas and Peligot, in the *Ann. de Chimie*, vol. LVIII., that they profess to have obtained it, although not in a state of absolute purity.

These homologous or polymeric bodies are as follows:

Methylene.....	$C_2 H_2$
Olefiant gas	$C_4 H_4$
Propylene	$C_6 H_6$
Quadrocarburet of Faraday.....	$C_8 H_8$
Oleine of Fremy (<i>Ann. de Pharm.</i> XX.)	$C_{12} H_{12}$
Naphthene? (<i>Pelletier, Comptes Rendus</i> IX.)	$C_{16} H_{16}$
Paramylene?.....	$C_{20} H_{20}$
Cetylene (Dumas).....	$C_{32} H_{32}$
Metamylene?	$C_{40} H_{40}$
Paraffin, Ceroten, (<i>Brodie</i>)	$C_{54} H_{54}$
Paraffin, Melin, (<i>ditto</i>)	$C_{60} H_{60}$

Note to p. 313, chapter X.

On the distinction between Allotropic, Isomeric, and Dimorphous bodies.

We may distinguish three distinct sets of bodies by the names of *isomeric*, *allotropic*, and *dimorphous*.

By the 1st term, *isomeric*, we mean bodies composed of the same elements in the same proportions, but exhibiting perfectly distinct properties, and not liable to pass into each other. In this case then we conceive, that the bodies respectively produced in the manner supposed, may present, according to the mode of grouping or aggregation of their particles, such entirely different characters, as entitle them to be regarded as chemically distinct, and nowise related to each other.

By the 2nd designation, viz. *allotropic*, we mean those in which a different arrangement of particles has produced some modification of the properties of a body, but not an assumption of new and distinct ones; and in which the bodies are easily made to pass from one condition to the other. By the 3d, or *dimorphous*, we mean bodies susceptible merely of such a mechanical change, as is productive of a distinct mode of crystallization, a difference in hardness, colour, &c.; but which leaves the chemical properties unaffected.

Note to chapter X. p. 322.

On Berthollet's views respecting chemical combination.

Since the general reception of the Atomic Theory, the views of Berthollet respecting the influence of quantity upon chemical combination, appear to have been abandoned in this country, from an impression that the latter doctrine is inconsistent with the former.

But this is not altogether the case, for, even if we admit Berthollet's hypothesis, it would not necessarily follow, that

the combinations between bodies should be indefinite; it is conceivable, that they still may take place in atomic proportions.

This perhaps may be explained by a few examples. Berzelius mentions (in a memoir on some compounds that depend on weak affinities*) that if magnesia be thrown down from its solution in sulphuric acid by ammonia, it retains a portion of acid, amounting to about two per cent. of the whole quantity, the composition of the precipitate being magnesia 67.5 per cent., sulphuric acid 1.6, water 30.9. He therefore concludes that one atom of subsulphate of magnesia is combined with a great number of atoms of hydrate of magnesia. Now the reason why the ammonia was unable to separate this last portion of acid, by the same attraction which enabled it to abstract from the earth the remainder, could only be, either the superior affinity subsisting between a small number of atoms of sulphuric acid for a large number of atoms of magnesia, or that of a small quantity of subsulphate of the earth for a larger one of hydrate. Berzelius has shewn, that this union of one atom of one substance with a very large number of atoms of another takes place frequently: thus in the sulpho-salts, one atom of sulphuret of potassium may combine with 24 of sulphuret of arsenic.

In order to reconcile these statements with Dalton's views, we may perhaps suppose, one atom of the triple salt composed of sulphuret of potassium and sulphuret of arsenic to be combined with several of the sulphuret of arsenic alone; and in the foregoing instance, a single particle of common sulphate of magnesia to be united with several of the hydrate. In either case, the inference would be the same; viz. that the affinity of a number of atoms of one salt for a smaller number of atoms of the other, added to that of the constituents of the latter, one for the other, was sufficient to counteract the influence of the substance added.

Berzelius was disposed to extend Berthollet's views gene-

* Edinburgh Phil. Journal, vol. i. 819.

rally to salts held in solution in the same menstruum, and consequently to the case of mineral waters.

Thus he conceived, that in such cases, as many salts really exist, as could be formed out of the whole number of acids and of bases present; the relative proportion of these salts depending upon the balance between the quantity of these latter, and their relative tendencies to combine.

"If," says Berzelius, "the physician inquires of the chemist, what the proportion which these salts bear to each other in any given case may be, the latter must reply, that this is a question as to which we are at present entirely in the dark, as the proportions depend, not only on the quantity of the acids and bases present, which admits of being ascertained, but also upon the relative force of affinity subsisting between the one and the other, for determining which we have as yet no data whatsoever."

Now, granting the above to be a correct statement, this practical consequence seems to follow, which physicians would do well to bear in mind in their imitations of natural springs; namely, that the medical properties of two mineral waters, exactly agreeing in the nature and quantity of the active ingredients that can be obtained from them by analysis, may be materially modified by the introduction of a third substance, although one in itself perfectly inert.

Let us, for example, suppose, that we have dissolved in two equal portions of water the same quantities of muriate of magnesia and sulphate of soda, both of which exert in different ways a certain action upon the animal functions, and that we afterwards introduce into one of the solutions a little carbonate of lime, a substance not known to possess any medical virtue whatsoever. It is clear, that according to the old hypothesis the two waters ought to produce similar effects upon the constitution; but, according to the views we have been advocating, it may be conceived, that the ingredients of the carbonate of lime would in part be divided between the other constituents of the mineral water, so as to

diminish the actual quantities of sulphate of soda and muriate of magnesia, and to substitute for them a small proportion of carbonate of soda and muriate of lime; salts which might communicate to the water, properties that did not belong to it before.

Thus, to take the case of the Buxton water. Dr. Scudamore stated, that every gallon furnished him on evaporation with the following saline principles; viz.

	Gr.	Containing of	
		Acid.	Base.
Muriate of magnesia.....	0.58	0.377	0.203
Muriate of soda	2.40	1.290	1.110
Sulphate of lime	0.60	0.352	0.248
Carbonate of lime.....	10.40	4.570	5.830

But as sulphate of soda is a more soluble salt than sulphate of lime, he chooses to represent the composition of the water as follows, consistently with the views of Dr. Murray, who contended, that the ingredients of a mineral water combined in such a manner as to form the most soluble salts, viz.

Sulphate of soda	0.63
Muriate of lime	0.57
— soda	1.80
— magnesia	0.58
Carbonate of lime	10.40

In reality, however, all that we are warranted in asserting, if we wish to steer clear of hypothesis, is, that the water contains the following acids and bases; viz.

Sulphuric acid.....	0.352	Magnesia	0.203
Muriatic acid	1.667	Soda,	1.110
Carbonic acid	4.570	Lime	6.078

which, if the views that we have just brought forward are correct, would constitute the following salts in unknown proportions; viz.*

Sulphates

* In the above, I have chosen to adhere to the old nomenclature respecting the muriates, from a wish merely to simplify the statement as much as possible.

Sulphates of magnesia.

_____ soda.

_____ lime.

Muricates of magnesia.

_____ soda.

Muricates of lime.

Carbonates of magnesia.

_____ soda.

_____ lime.

Now, if we were to prepare an artificial water, by dissolving together salts similar to those extracted from the Buxton spring, but leaving out the carbonate of lime as inert, the mixture would contain only,

Muriate of magnesia.

_____ soda.

Sulphate of magnesia.

_____ soda;

and would thus be deficient in two active ingredients, muriate of lime and carbonate of soda, which its natural prototype possesses*.

In a memoir, which I published at an early period of my life, "On the methods of separating Lime from Magnesia," I alluded to a difficulty, which occurred to me in separating completely by the usual re-agents magnesian salts from calcareous ones, or *vice versâ*, as illustrative of the influence of quantity on chemical attraction.

Thus, a solution combining 1 grain of sulphate of lime, and 100 grains of sulphate of magnesia, in 1 ounce measure of water, was not rendered turbid by oxalate of ammonia till many hours afterwards; although the same solution of lime, without the magnesia, became so immediately under the same treatment.

Bicarbonate of ammonia, which with magnesia forms a compound readily soluble in water, when added to a solution containing a magnesian, as well as a calcareous salt, appears to carry down a small portion of the magnesia with the carbonate of lime precipitated. May not this be in some measure connected with the isomorphism of the two earths.

* See an article by the author, in the second number of the London Review, on Mineral Waters.

GLOSSARY.

As a few of the following technical terms may not be interpreted in the preceding pages, I have been induced to annex a Glossary, which, at the same time that it defines those expressions that appear most to require elucidation, will also serve the purpose of an index; reference being generally given to the page of the work in which each term therein used is explained.

ACIDS, substances having the property of combining with, and neutralizing alkalies, or other bases. For the reasons which lead us to place Silica in this class, see p. 392.

ALBUMEN, a proximate principle of animal matter, which forms the white of eggs, and occurs in large quantity in the blood.

ALCOHOL, used as a generic term for a class of bodies defined in p. 221. The body commonly called *alcohol*, derived from the fermentation of saccharine matter, is distinguished as *wine-alcohol* or *wine-spirit*.

ALDEHYDE, a generic term for a class of bodies derived from any one of the alcohols, by the abstraction of 2 atoms of hydrogen. See pp. 221 and 232.

ALKALIES, bodies capable of neutralizing acids, of dissolving in water, of changing vegetable blues to a green, and of forming soluble soaps with oily matters. The constitution of those belonging to the vegetable kingdom is dwelt upon in p. 234 et seq.

ALLOTROPISM, the property of assuming two or more dis-

tinct forms, accompanied by a certain change of chemical properties. See this term defined in p. 490.

ALLOY, a compound of any one metal with any other, excepting with mercury.

AMALGAM, a compound of any metal with mercury.

AMIDE, an hypothetical compound, consisting of two ingredients, one of which is constituted of the elements of ammonia with 1 of its atoms of hydrogen removed.

AMIDOGEN, the name for that hypothetical compound of $H_2 N$ which is supposed to produce an amyde. See, for both these terms, p. 248.

AMYLACEOUS MATTER, matter consisting of starch.

AMYLE, the radical or base of potato-spirit. See p. 227.

ATOM, a portion of matter, not admitting of further division.

When it becomes necessary to be more precise, the term *ultimate atom* is employed. See p. 158.

ATOM, CHEMICAL, a portion of matter not admitting of further division by *chemical means*. See p. 160.

ATOM, PHYSICAL, a portion of matter not admitting of further division by the agency of heat. See p. 140.

ATTRACTION, ADHESIVE, the force that binds together masses of matter, or causes their surfaces to adhere. See p. 314.

— **CHEMICAL or ELECTIVE**, the force that binds together the particles of heterogeneous bodies. See p. 323.

— **COHESIVE**, the force that binds together the particles of the same body.

BINARY THEORY OF SALTS. See this explained in p. 335 et seq.

CATALYSIS, an expression for the *fact*, that a body decomposes another, without entering into combination with any one of its constituents. See p. 340.

CASEINE, the nitrogenised principle contained in cheese, chemically the same as Legumine present in beans and many other vegetables.

CELL DEVELOPMENT; for this consult Schleiden's, Hensley's, or Lindley's Botany.

CEMENTATION, the process of forming steel, by causing carbon to unite with iron at a temperature below the fusing point of the latter.

CETYLE, the base or radical of ethal, obtained from spermaceti. See p. 228.

COMBUSTION, a process effecting the union between two antagonistic bodies, and accompanied with the disengagement of more or less heat. In ordinary combustion oxygen is one of the bodies concerned.

DIFFUSIBILITY OF SALTS; see p. 326.

DIMORPHISM, the capacity of assuming two distinct crystalline forms not related; see p. 123: and for the distinction between it and allotropism, see Additional Notes, p. 490.

ELECTRODE, the surface which conveys an electric current into and from the liquid to be decomposed—distinguished into *anode* and *cathode*, or positive and negative electrode. See Faraday's Memoirs in the Philosophical Transactions, or the abstracts of them contained in all systems of chemistry.

ELECTROLYSIS, decomposition by means of, or through the agency of, electricity.

ELEMENT, a body not hitherto decomposed. See p. 427 et seq.

ENDOSMOSE, the tendency of an external fluid to pass into a cell formed by a vegetable or animal membrane, and thus to render it turgid; when not counteracted, by an equal tendency in the fluid within to pass out through the same membrane, which is called *exosmose*. This principle, and its consequences, are explained in most works on vegetable and animal physiology.

EQUIVALENT, the weight of any body which is just sufficient to destroy or neutralize the properties of another. Employed therefore as synonymous to the term *Atom*. See p. 57.

ETHAL, the alcohol of cetylc. See p. 228.

ETHER, in the sense in which it is employed in this work, implies the oxide of the radical ethyle. See p. 220.

Ethers however, as will be seen in the work, are distinguished into simple and compound, and it is to the former kind that the definition applies.

ETHERINE, the basis of wine-alcohol, according to Dumas.

It must not be confounded with Ethyle. See p. 254.

ETHYLE, the radical, which, according to Liebig, produces ether with oxygen. See p. 214.

EXOSMOSE, see **ENDOSMOSE**.

FERMENTATION, in a general sense, means a change produced in an organic body, owing to a process set up in it through the presence of a foreign substance, itself in the act of undergoing a chemical change. Thus, vinous fermentation is a particular case only of this general principle. See p. 348.

FIBRINE, the principal nitrogenized ingredient of the blood, and of the flesh of animals.

FORMULA, EMPIRICAL, an expression merely of the composition of a body, or of the number of atoms of each ingredient of which it consists. See p. 297.

FORMULA, RATIONAL, an expression, not merely of the composition of the body, but of the manner in which its ingredients are supposed to be combined. See p. 297.

FUSEL OIL, also called potato spirit, the alcohol of the radical amyle. See p. 227.

GELATINE, the principle in animal jelly, present in the tendons, ligaments, &c., and constituting much of the organic matter of bones. For its composition, &c. see p. 372.

HEAT, SPECIFIC, the relative quantity of heat necessary to raise each body an equal number of degrees of temperature. See p. 148.

HEMIEDRAL CRYSTALS, those crystals, half of whose similar planes or angles are modified independently of the other half. See p. 264.

HOMOLOGOUS BODIES, bodies formed upon the same plan or model, having their particles arranged in the same manner, although not the same in number. Examples: wood spirit, wine spirit, fusel oil, ethal. See Additional Notes, p. 485.

HYDRATE, a body in which water acts the part of an acid.

HYDROCARBURET, a compound of hydrogen and carbon in any proportion whatsoever.

HYDROSILICATES, a compound of a silicate with water. See p. 405.

IMIDOGEN, a compound of which the basis is ammonia, but in which two of its atoms of hydrogen are removed.

ISOMERISM, the property of forming a body differing in chemical characters from another which possesses the same atomic constitution.

ISOMERIC BODIES, bodies of the same composition, but different properties. The whole of chapters VII. and VIII. is devoted to the explanation of this subject.

ISOMORPHISM, the property of assuming the same form, and in some respects analogous properties, as another body, the composition of which is different. See p. 168.

ISOMORPHOUS BODIES, bodies circumstanced as above.

KAKODYLE, a body made up of arsenious acid and an hydrocarbon, which together form a compound radical. It is elsewhere spelt *cacodyle*. See p. 219.

LEGUMINE, a vegetable principle present in most leguminous plants, and considered identical with caseine.

MARSH GAS, synonymous with light carburetted hydrogen, or $C_1 H_2$.

MERORGANISATION, a fitness in a body, to become part of a living substance, by being itself partly organized already. See Dr. Prout's views on this subject explained in p. 420.

METAMERISM, difference of properties in bodies similarly constituted, arising out of a difference in the arrangement of their particles with reference to each other. See p. 265.

METHYLE, an hydrocarbon, the basis of wood spirit, according to Liebig. See p. 226.

METHYLENE, the basis of wood-spirit according to Dumas. See p. 234, where it is erroneously stated to be an hypothetical principle, for Dumas and Peligot assert that they have obtained it. It must not be confounded with methyle.

MOLECULE, used frequently as a synonym for atom; but strictly speaking, a group or cluster of atoms associated together in combination. It would therefore correspond to the term *chemical atom*.

NASCENT STATE, the condition of a body, at the instant when it is set free from a state of combination, and before it has absorbed its latent heat.

NOTATION, CHEMICAL, for the three modes of noting the names and proportions of the elements which constitute a compound, see chap. III.

NUMBER, ATOMIC, the number of atoms contained within a given space.

PARAFFIN, a principle discovered by Reichenbach in tar; for its relations to wax, see p. 258.

PLESIOMORPHISM, sometimes used to designate the condition of a body, which assumes a crystalline form similar to another, but not identical; plesiomorphous bodies are therefore distinguished from isomorphous. See p. 175.

POLARITY, the quality of possessing, or acquiring under particular circumstances, opposite powers or properties on opposite sides or portions of its surface. Thus electricity, magnetism, &c. are *polar* forces, because they induce opposite states in the same body at its opposite extremities. See p. 352. Dr. Prout's Bridgewater Treatise, 1st edit., may be consulted with advantage on this subject.

POLARISATION OF LIGHT, the process of so altering the condition of a beam of light, as to cause it to acquire different properties on its opposite sides, so as in certain positions to be affected by reflecting or refracting bodies in

an unusual manner. For the laws or principles of the polarisation of light, see any work on Optics; for its application to chemistry, see Sir Robert Kane's *Elements*, Fownes' *Manual*, &c. Allusion is made to it, as a means of distinguishing tartaric and racemic acids, in p. 263.

POLYMERISM, the case of bodies possessing the same composition but different properties, in which the cause of the difference is referred to the relative degree of aggregation in the two. See p. 265.

PROPORTIONS, DEFINITE, law of, explained in chap. II.

PROTEINE, according to Mulder, the basis of albumen, fibrine, and caseine, the three nitrogenized principles present in the animal organization. Liebig however does not admit of its existence. See p. 420.

PYROXYLOUS SPIRIT, also called wood-spirit, an alcohol derived from methyle. See p. 226.

RADICAL, the basis of a chemical combination; distinguished into *simple* and *compound*; *simple* radicals being the so-called elements of matter; *compound* ones, being bodies which, although consisting of at least two ingredients, perform in combination the same functions with reference to organic substances which the elements do to mineral ones. See p. 211.

REDUCTION, a process in which oxygen is separated from a combustible body. It is therefore the reverse of combustion. See p. 367.

SALT, a body formed by the union, either of an acid with an alkali, earth, or metallic oxide; or else of a simple body of the chlorine family with a metal: the former being called oxygen salts, the latter haloid ones. They are either simple or double. By reference to p. 336 may be seen an attempt to reduce them all to one head.

SCALENE PYRAMID, p. 122, a pyramid comprised within scalene triangles, or triangles with sides and angles unequal.

SUBSTITUTION, the replacement of one element or radical by another. See, for the law of substitution, p. 188.

SULPHUR SALT, a salt in which sulphur acts the same part as oxygen does in the oxygen salts; being composed of one sulphuret combined with another; the first in the same electric condition as an acid, the second in the same as a base.

SYMBOLS, letters denoting the various elementary bodies and radicals known in chemistry. See p. 103.

TRACHYTE, a rock proceeding from volcanic action, and consisting principally of glassy felspar. See p. 416.

TYPE, CHEMICAL, the imaginary structure or arrangement of the particles in an organic compound. See p. 203.

VITAL AFFINITY, a force of attraction, supposed to belong to the particles of matter so long as they are under the influence of the powers of life. See p. 359 et seq.

VOLUME, ATOMIC, the space occupied by an atom, together with its surrounding atmosphere of heat. See p. 275.

— **EQUIVALENT**, a term used by some writers in the same sense, as that in which I have employed the expression, *atomic* volume.

WATER OF CRYSTALLIZATION.

——— **BASIC.**

——— **CONSTITUTIONAL.**

The sense in which these terms are employed is explained in p. 331 et seq.

WEIGHT, ATOMIC, the weight of the atom of a body, as compared with some one standard, which is generally either hydrogen or oxygen.

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